Energy
National Research Programmes 70 and 71

Synthesis

Energy Networks

Energy Networks

This thematic synthesis concerns the technological, ecological and social framework conditions for new, innovative energy infrastructure, plus the associated drivers and barriers. The main focus is on technical feasibility, economic viability and spatial impact.

1. The energy grids are not yet fit for the future

Switzerland's energy grids are reliable and stable – but they are facing new challenges. These include the fact that the new renewable energy sources, namely photovoltaic systems and wind farms, only produce electricity on an irregular basis. Greater flexibility is therefore required in the energy grid: with new storage solutions for electricity and heat on the supply side and automated load management on the demand side. The potential synergies between the various energy sources must also be exploited.

1.1. Core messages

The following four core messages in the area of energy grids can be derived from the research work of the NRP Energy.

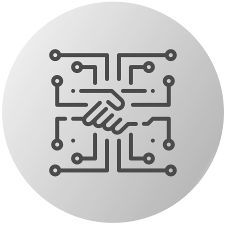
1. **The energy supply system of the future is an overall system** As there will be ever more decentralised energy providers – including private PV systems linked to the grid – the transmission grid and distribution grids need to be planned and operated on an integrated basis. The integral consideration of both levels also offers many new opportunities, for example with respect to flexibility. The linking of various energy sources such as electricity, gas and heat – so-called sector coupling – is also opening up new possibilities for the reconciliation of supply and demand.
2. **Flexibility is a prerequisite for the use of solar and wind energy** The expansion of solar and wind energy requires greater flexibility in the electricity grid. This flexibility can be created by energy providers or consumers. On the supply side, new storage technologies can offer attractive solutions, while on the demand side digitalisation is opening up new opportunities for automated load management. However, flexibility comes at a price which needs to be communicated transparently and charged for in line with market conditions.
3. **Comprehensive digitalisation is key to success** The increasing decentralisation of energy provision and storage combined with a considerable increase in the number of prosumers and the high volatility of solar and wind energy mean that new grid control and load management systems are required. This enormous challenge cannot be handled efficiently without comprehensive digitalisation. The requirements for effective digitalisation include the accessibility of relevant data for the respective stakeholders and continued compliance with data protection requirements.

4. **No supply security without grid expansion** The planned expansion of the Swiss transmission grid is an important prerequisite for supply security. The expansion plans need to be updated on an ongoing basis in order to take account of new conditions and developments in Switzerland and abroad. The energy network with neighbouring countries makes an important and cost-efficient contribution to supply security and to increasing flexibility on the supply side. A prerequisite for the expansion is a high level of social acceptance with respect to the grid infrastructure.

1.2. Key recommendations

Utilise the synergies of various energy sources!

Electricity, gas and heating grid operators clarify which advantages and disadvantages would emerge from the overall optimisation of all energy grids at a regional level. The synergies of sector coupling need to be utilised on a systematic basis.



Make secure use of digitalisation!

It is essential to make use of the opportunities offered by digitalisation and to use innovative tools. To this end, information and communication technologies, data-based instruments and artificial intelligence must be increasingly used for the electricity supply.

Create and sell flexibility!

The higher the number of energy providers with fluctuating production levels, the greater the need for flexibility!

All recommendations relating to the topic of “energy grids” are formulated in full in the “Recommendations” section of this synthesis. Of this total of eight recommendations, three are so-called key recommendations that are especially relevant with respect to the successful implementation of Energy Strategy 2050.

Utilise the synergies of various energy sources! Electricity, gas and heating grid operators clarify which advantages and disadvantages would emerge from the overall optimisation of all energy grids at a regional level. The synergies of sector coupling need to be utilised on a systematic basis. The projects of the NRP Energy show that an integral overall view of the energy system is beneficial for energy grids. In order to be able to optimise the energy system in its entirety, the parochial thinking of the individual energy sources and consumers needs to be abandoned and replaced with an overall strategy.

Make secure use of digitalisation! It is essential to make use of the opportunities offered by digitalisation and to use innovative tools. To this end, information and communication technologies, data-based instruments and artificial intelligence must be increasingly used for the electricity supply. At the same time, the risks associated with digitalisation need to be countered:

- Risks of cyber attacks that pose a massive threat to supply security.
- Risks for privacy and personal freedom due to inadequate data protection.

Create and sell flexibility! The higher the number of energy providers with fluctuating production levels, the greater the need for flexibility. The question arises as to how flexibility should be traded and remunerated in future – for example in line with the current regulations regarding the provision of frequency control. The linking of energy systems provides significant potential for flexibility. Energy storage devices can also increase flexibility. During the planning of new plants and the conversion of existing ones, energy providers attach special importance to the creation of additional flexibility. They develop new business models in order to be able to offer flexibility as a service.

2. New dynamics in energy grids

The Swiss transmission grid for electricity will be expanded over the coming years. However, far greater efforts and investment in the energy grids will still be required if it is to meet the specifications stipulated under Energy Strategy 2050.

Energy grids

2.1. Energy grids

Energy grids connect energy providers to energy consumers. In doing so, they overcome spatial distances. However, with the increasing use of renewable energy sources such as solar, wind and biomass energy, overcoming the time gaps between the provision and consumption of energy is rapidly gaining importance. In the past, this task was primarily fulfilled by storage and pumped-storage power plants. In future, however, other storage technologies will be required. These can be part of the energy grid. The future highly dynamic energy system must be operated optimally from a technical and economic perspective; digital monitoring, control and regulation mechanisms will play a decisive role here.

An energy grid generally comprises three components:

Energy distribution: Energy is generally distributed through power lines or pipelines that are designed hierarchically: transmission and transport lines for the distribution of large quantities of energy over extended distances and regional or local distribution networks for fine distribution to the individual energy consumers. The energy distribution process also involves secondary plants such as substations, transformers and pressure reduction facilities.

Energy storage: Storage capacity integrated in the energy grid, for example central battery units, compressed air reservoirs, gas tanks and pipes as well as underground storage tanks.

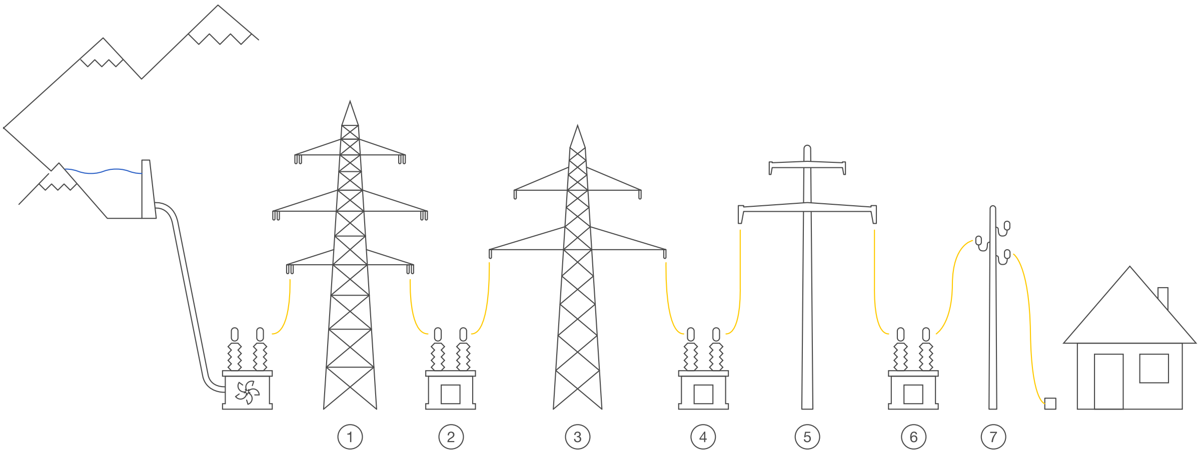
Energy management: Control systems for the monitoring, controlling and regulation of energy flows in the energy grid. Due to digitalisation, these control systems are becoming ever more sophisticated.

There is a high level of interdependence between the energy grid and energy provision, on the one hand, and energy consumption, on the other.

It is primarily electricity, heat and gas that are transported in energy grids. In Switzerland, these three grids have been developed independently of one another and are still also operated on a stand-alone basis. This means that considerable synergy potential is not being utilised. Numerous projects in the NRP “Energy” are therefore focussing on adopting an overall view of the energy system and the benefits that this generates.

Supply security # Energy grids

2.2. The electricity grid



Voltage levels. 1st: extra-high voltage level: it takes on electricity from Swiss power plants and abroad with voltages of 220 kV or 380 kV. 3rd: high-voltage level: the electricity flows with a voltage of between 36 kV and 150 kV. 5th: medium-voltage level: the electricity flows with a voltage of between 1 kV and 36 kV. 7th: low-voltage level: the electricity reaches sockets with a voltage of less than 1 kV. 2nd, 4th, 6th: transformer levels: these transform the electricity to the next lower or higher level. *Source: Swissgrid*

The entire Swiss electricity grid measures more than 202,000 kilometres.[1] It is divided into seven levels:

Level 1 is the transmission grid or extra-high voltage grid. It belongs to Swissgrid and comprises approximately 6,700 kilometres of lines as well as 141 substations.[2] The electricity from Swiss power plants and from abroad flows through the grid with voltages of 220 kV and 380 kV.

Levels 3, 5 and 7 together form the distribution grid. In Switzerland, there are around 650 distribution grid operators who are each responsible for their respective grid segment. Level 3 is the high-voltage level with voltages of between 36 kV and 150 kV. The medium-voltage level 5 only transports electricity at voltages ranging from 1 kV to 36 kV. Level 7, the low-voltage level, finally transmits electricity to energy consumers at a voltage of below 1 kV where it can be used with 230 V.

Between these levels, the transformer levels 2, 4 and 6 regulate the voltage.

The Swiss electricity grid is based on alternating current. This is easier to transform than direct current and therefore makes possible the hierarchical development of the grid in voltage levels. Europe’s electricity grid, in which Switzerland plays a central role with 41 cross-border lines, operates at a frequency of 50 hertz. It needs to be kept stable. This is because rapid and significant fluctuations can, for example, lead to damage to large machinery and put supply security at risk.

In order to keep the frequency stable, electricity production and consumption must always be balanced. The Swiss grid is therefore meticulously mapped by 40,000 measurement points; this means that in the vast majority of cases fluctuations can be registered in a matter of seconds and even predicted. Thanks to this comprehensive monitoring, the Swiss transmission grid is deemed to be very stable and reliable.

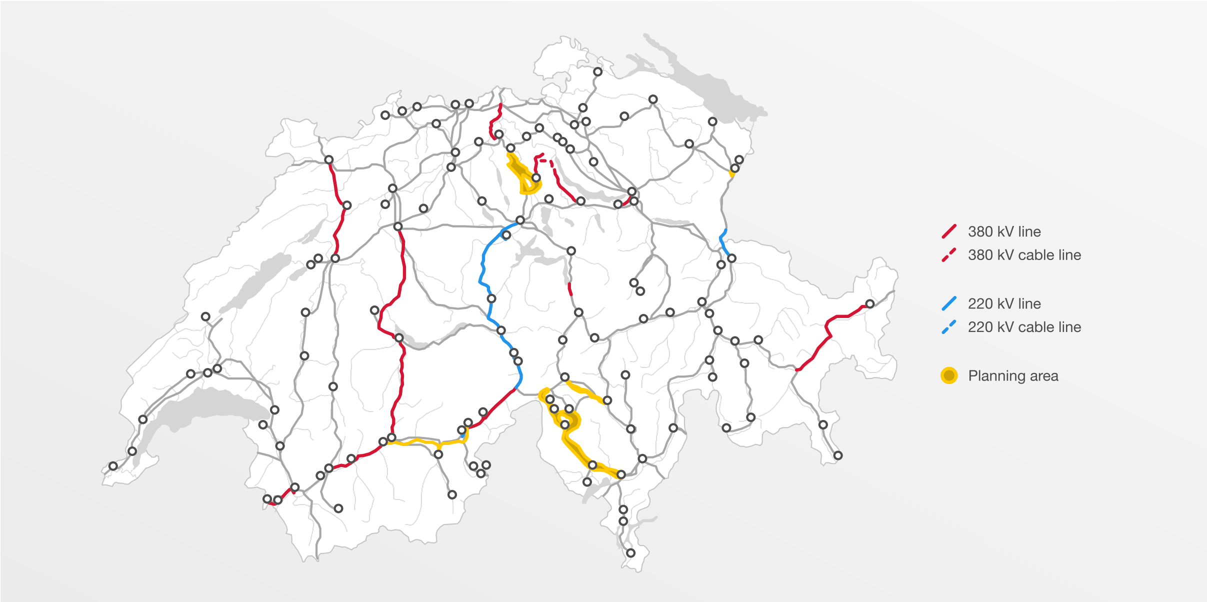
Storing large volumes of electricity is challenging. Pumped-storage power plants presently offer the greatest possibilities. However, current electricity prices mean that they are not economically viable. “Power-to-gas” storage is a promising solution: hydrogen or methane is produced using excess solar electricity before being stored in tanks and finally being converted back into electricity via a gas turbine or fuel cell.

Notes and References

1 ElCom 2018; Report on the activities, section 3.1
2 Swissgrid 2015; Strategic Grid 2025

Supply security # Energy grids

2.3. The electricity grid is being expanded



Expansion of electricity grid. *Source: https://www.swissgrid.ch/en/home/projects/project-overview.html*

According to the “Electricity grid strategy” passed by the Swiss parliament in 2017, Swissgrid is to create a multi-year plan for a grid expansion on the basis of the federal government’s Energy Perspectives for 2050 and the plans of the European Transmission System Operators. The planning for the Strategic Grid 2025 comprises a total of 17 conversion or expansion projects distributed throughout Switzerland. Most projects relate to increasing the voltage from 220 kV to 360 kV for existing lines with the local adjustment of routes. There are, however, also plans for completely new transmission lines, such as the approximately 70-kilometre-long 380 kV line in Valais which stretches from Chamoson to Mörel via Chippis.

Underground transmission lines are also being increasingly considered during the planning process. The construction of an initial 1.3-kilometre-long cable sector on the “Gäbihügel” between Bözberg and Rinikon was commenced in August 2018 as part of the Beznau–Birr grid project.

The figure shows the planned expansion.

The biggest problem faced by the conversion and expansion projects is the long planning and approval period, which amounts to more than ten years for many projects. Once approval and authorisation have been granted, the construction process does not take long.

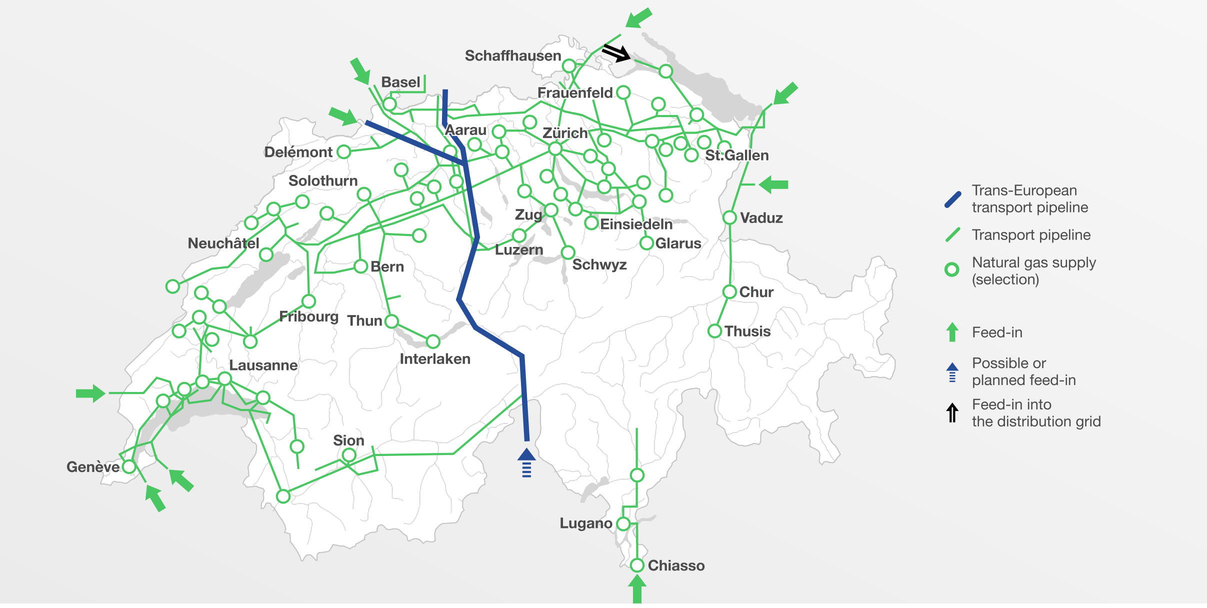
The distribution grid operators (grid levels 3 to 7) are also obliged to draw up a multi-year plan – in order to ensure a secure, high-performance and efficient electricity supply in their catchment area. Here, the expansion is primarily determined by new settlements, the relocation - in and out - of businesses with high energy requirements and the development of new energy sources. At these grid levels, the “Electricity grid strategy” states that line projects should generally be executed as underground cables provided the cost of these cables does not exceed twice that of overhead lines.[1] The use of digital control and regulation systems can contribute to reducing the need for expensive grid expansions, especially at grid levels 3 to 7.

Notes and References

1 SR 734.31 Ordinance on Electric Lines and Cables, amendment of 3 April 2019 regarding Art. 11b(1)

Market # Energy grids # Europe / EU # Energy storage

2.4. The gas grid



Gas grid. *Source: www.iet.hsr.ch/fileadmin/user-upload/iet.hsr.ch/power-to-Gas/Kurzberichte/05_erdgasinfrastruktur_Schweiz.pdf*

Natural gas covers 14 % of Swiss final energy consumption. Domestic natural gas reserves are too small for economically viable extraction; only around 1 % of the gas fed into the grid originated from domestic biogas production in 2017.[1] Natural gas has to be fully imported – primarily from the EU, Russia and Norway. The gas is imported via 16 border crossing points via which Switzerland is connected to the European gas transport grid.[2] Natural gas is currently supplied to more than 900 municipalities by 120 local providers.

The gas grid also has a hierarchical structure: in 2016, the transport grid with a pressure of more than 5 bar comprised pipelines with a length totalling 2,243 kilometres; the distribution grid with pressures of under 5 bar is around 17,500 kilometres long. Pressure reduction stations ensure that natural gas has a pressure of less than 1 bar when it is received by energy consumers. Some 145 natural gas service stations supply energy to gas-powered means of transport, while 27 biogas plants make a domestic contribution to the gas supply. The gas grid is not comprehensive – certain mountain regions are not connected. There is no basic service mandate in place for gas.

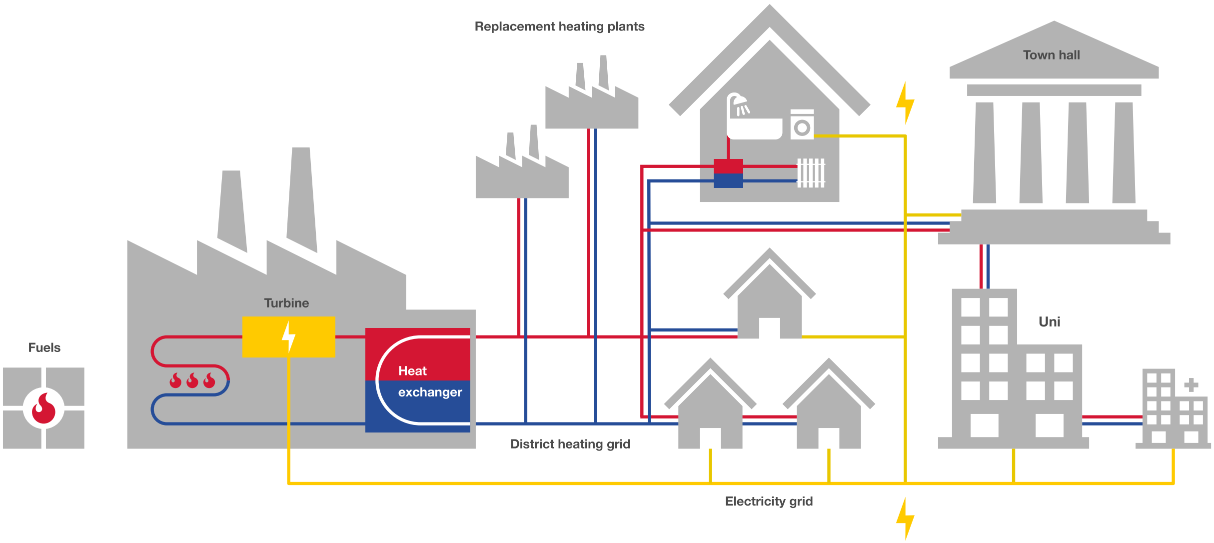
Six smaller natural gas storage facilities serve as a grid buffer in order to balance out fluctuations in daily requirements. The storing of larger quantities of gas in the natural gas grid is not planned. Among other reasons, this is because the geological conditions for underground and pore storage facilities are lacking. In Europe, the largest natural gas reserves are stored by Germany and Italy. These reserves are primarily used as a store of value: the natural gas is purchased at low prices during the summer and stored – and resold in winter at higher prices when there is significant demand. Gas storage could also become an issue in Switzerland in future as “power-to-gas” solutions allow sustainably produced electricity to be converted into gas and to be stored for as long as necessary.

Notes and References

1 https://gazenergie.ch/de/news-events/news/detail/news/11-prozent-mehr-schweizer-biogas-eingespeist/
2 Erdgas/Biogas in der Schweiz. Ausgabe 2018. VSG-Jahresstatistik.

Cold / heat   # Heating   # Energy grids

2.5. District heating grids



Model of a district heating grid for which the heat is generated in a waste incineration plant. *Source: www.heizungfachsanierung.ch/de/arten_heizsysteme/fernwaerme*

A district heating grid provides heating from a central plant to consumers via isolated pipelines – in the form of hot water. For energy consumers, district heating has the advantage that it means they do not require either their own heating system or their own heating medium reserves.

The first projects were realised 50 years ago – primarily in connection with waste incineration plants.[1] However, district heating and heating grids do not play a major role in Switzerland at present. Only 4.2 % of all residential buildings are connected to district heating grids.[2] While this figure has more than tripled since 1990, individual heating systems remain the first choice.

The most important primary energy for district heating is waste heat from waste incineration plants followed by natural gas, wood and waste heat from nuclear power plants. Around one-third of the primary energy originates from fossil fuels. This share should be reduced considerably.[3]

Steel tanks with water as a medium have prevailed for heat storage within district heating grids.

The principle of district cooling works similarly to that of district heating. District cooling can be produced in an environmentally friendly fashion using absorption chillers. These are operated with waste heat rather than electricity and produce the district cooling by means of thermal compression.[4]

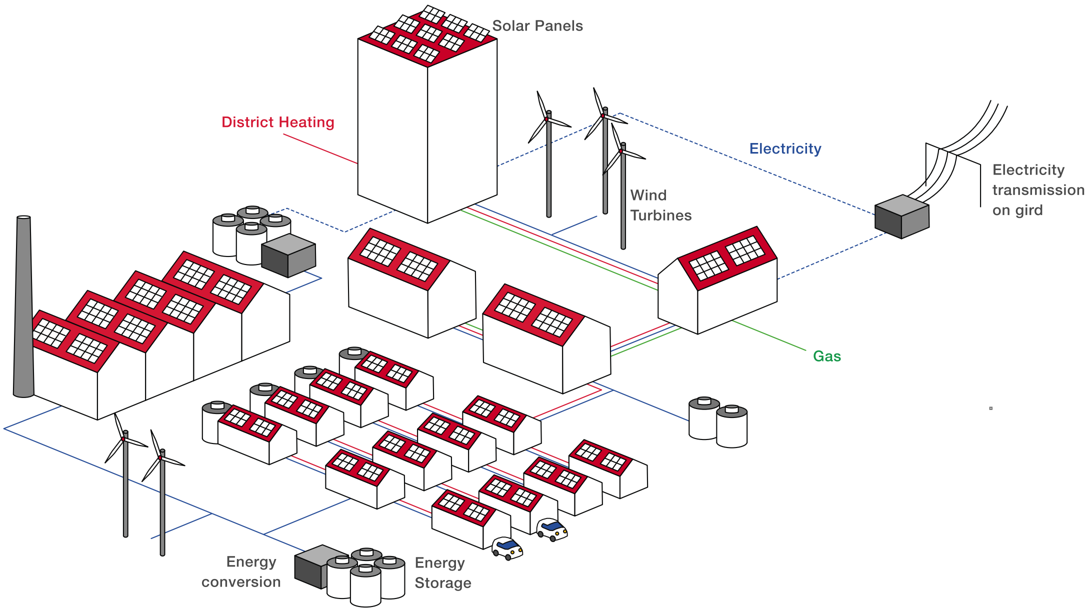
For the future, scientists expect extreme weather conditions that will see a decline in heating requirements and lead to a rise in cooling needs. Central district cooling from absorption chillers is between five and ten times more efficient than a conventional individual solution.[5] Especially in densely populated areas, they can considerably reduce local electricity consumption and make the expansion or reinforcement of the electricity grid unnecessary.

Notes and References

1 World Energy Council Switzerland; http://www.worldenergy.ch/seiten/publikationen/wec-switzerland/energiestatistik-schweiz/energietraeger/Fernwaerme/?oid=139&lang=de
2 https://www.bfs.admin.ch/bfs/en/home/statistics/construction-housing/buildings/energy-field.html
3 Swiss District Heating Association 2018; Annual Report 2017;https://www.fernwaerme-schweiz.ch/fernwaerme-deutsch-wAssets/docs/Verband/Jahresbericht-Dokumente-d/Jahresbericht_2017_d.pdf
4 Swiss District Heating Association; https://www.fernwaerme-schweiz.ch/fernwaerme-deutsch/was-ist-fernwaerme.php
5 https://www.fernwaerme-schweiz.ch/fernwaerme-deutsch-wAssets/docs/Fernwaerme_Flyer/Fernwaerme_d_Web.pdf

Sector coupling # Energy grids

2.6. Trend towards sector coupling



Model of a decentralised multi-energy hub system that is fed by numerous energy sources. *Source: Project "Multi-energy hub systems and society'*

Today, there is an ever-increasing tendency not to view electricity, gas and heating grids separately, but rather as an overall system. This approach is referred to as sector coupling – energy system integration and multi-energy hub systems are other terms used here. It is, however, not only about the linking of different energy sources, but rather also the integration of prosumers, industrial production processes and modes of transport (e-vehicles and hydrogen-powered vehicles).

There are two main reasons for the increasing interest in sector coupling.

1. Focus is being placed on services that provide the energy sources – and not the energy sources themselves. For example, heat can be delivered from the electricity, gas or district heating grid. Which energy source is appropriate in each case is dependent on the system, which must therefore be viewed integrally.

2. Some components are linked to more than one energy grid. Thermal power plants, for example, generate electricity that is fed into the electricity grid and heat that makes its way into the heating grid. In such cases, reference is made to cogeneration or combined heat and power (CHP). Other components that link energy sources are heat pumps, fuel cells and power-to-gas concepts.

The project "Sustainable decentralised power generation"[1] looked at what environmental and economic potential is offered by linking different energy sources in this way: on the basis of models and case studies, it was discussed in detail how a decentralised multi-energy hub system that coordinates the various existing and future technologies of very different energy sources can work – from the provision of the energy right through to its consumption. It is key that the economy and new business models are also taken into account in the considerations.

Notes and References

1 Project "Sustainable decentralised power generation"

Prosumers # Supply security # Decentralisation # Photovoltaics

2.7. Ever more stakeholders

The era during which there were energy providers on the one side and energy consumers on the other is over – especially in the electricity grid. More and more energy consumers are producing energy themselves – for example with PV systems. In 2017, 38 %[1] more small PV systems were installed on single- and multi-family dwellings than in the year before. The situation for the other grids is different. The gas grid is primarily fed from abroad; up to 2030, however, the share of biogas from Swiss plants is to be increased from the current figure of 3 % to 30 % of total consumption for heat production. Heating grids primarily operate at a local level and independently of each other.

On the one hand, the fact that consumers produce energy themselves relieves the burden on the grid as energy does not need to be transported over long distances. On the other, however, it poses the grid with new challenges. This especially applies to the electricity grid where the feeding in and consumption of electricity needs to be balanced.

Incorporating these so-called prosumers – producer-consumers – in the existing energy systems in an efficient and secure manner is one of the major challenges of the energy future. Energy grids will play a key role here. Their control systems enable various players with different technical characteristics, possibilities and economic goals to be linked to the same energy system. Along with the increase in the number of prosumers, however, fluctuations in production volumes also rise: solar and wind energy production volumes are dependent on the weather, meaning that it is almost or completely impossible to influence them. The reliability and robustness of the grids must therefore be increased. Smart grids should help in managing the grids in a flexible, efficient and needs-based manner. Digital platforms ensure good access to data and the rapid exchange of information between the many players.

Notes and References

1 Swiss Federal Office of Energy (FSOE) 2017; Markterhebung Sonnenenergie. Teilstatistik der Schweizerischen Statistik der erneuerbaren Energien.
https://www.swissolar.ch/fileadmin/user_upload/Markterhebung/Marktumfrage_2017.pdf

Market   # Europe / EU

2.8. Switzerland and Europe

When commissioned in 1958, the "Star of Laufenburg"[1] substation provided the basis for the operation of the international grid. *Source: Swissgrid AG*

The European electricity grid supplies more than 30 countries with around 530 million consumers. Switzerland is part of this grid. At present, it is connected to its neighbouring countries via 41 lines. Switzerland acts as a central hub for international electricity trading: on behalf of the European Transmission System Operators (ENTSO-E), Swissgrid is the coordination centre for Southern Europe. And Switzerland also plays an important role at an international level from a technical perspective: since 1958, the "Star of Laufenburg" substation has been an important centre of the European integrated electricity grid.

The generation of hydropower is just as seasonal as electricity consumption. This means that Switzerland is an electricity importer in the winter and electricity exporter during the summer. To ensure supply security, it is therefore essential that the Swiss electricity grid is connected to countries abroad. The Swiss transmission grid also plays a key role in the transit between neighbouring countries; Europe is therefore reliant on the Swiss electricity grid.

Even without EU membership, Switzerland is thus part of the European electricity system. Yet in the absence of an electricity agreement this participation will be restricted to the technical aspects of the electricity grid – despite the fact that Switzerland is a full member of the ENTSO-E. However, as electricity trading with Europe represents an important pillar of our efforts aimed at bringing about an essential increase in supply-side system flexibility, the speedy conclusion of the electricity agreement between Switzerland and Europe with respect to grid stability and supply security is of utmost importance.

Switzerland is ultimately completely reliant on foreign countries in the gas sector: the country’s requirement must largely be covered with imports.

The projects “Switzerland and EU energy policy”[2] and “Europeanisation of the Swiss energy system”[3] investigated political and market-related aspects of the future relationship between Switzerland and Europe with respect to Energy Strategy 2050. They reveal that the topic is very complex and is of great significance for the Swiss electricity market.

Notes and References

1 www.swissgrid.ch/en/home/operation/power-grid/star-of-laufenburg.html
2 Project “Switzerland and EU energy policy”
3 Project “The European electricity market: staying away will be expensive but will also open up room for manoeuvre”

Regulation # Supply security # Europe / EU

2.9. Supply security is the top priority

Irrespective of from which sources the Swiss population consumes its energy in future and how this energy is comprised: supply security will always be the top priority. This fact is anchored in the Energy Article of the Federal Constitution and in the Energy Act.

To ensure that supply security remains assured, Switzerland needs to look beyond its national borders. In the area of natural gas, where Switzerland is almost fully reliant on imports, international political developments as well as global gas market developments need to be closely observed. These developments, the involvement of Switzerland in the European market and coordination with other countries will be decisive factors for the future of the Swiss gas market.[1]

Even more important is the reliability of the electricity supply. This is the responsibility of the electricity sector. The federal government and the cantons need to create framework conditions and intervene if the companies within the electricity sector can no longer guarantee a secure electricity supply. The Federal Electricity Commission ElCom monitors supply security and can propose appropriate measures to the Federal Council as needed.

Investments of Swiss energy providers in solar facilities and wind parks in Northern Europe will be unable to make a notable contribution to supply security in Switzerland as the required transmission lines running through Germany will be unavailable in the foreseeable future. Even an electricity agreement with the EU will not solve all problems. This is because it will only guarantee *access* to the European market but will not assure Switzerland's electricity *supply*. There is therefore still a need for the internal provision of electricity.

A study conducted by the Swiss Federal Office of Energy (SFOE) does not view Switzerland's supply situation up to 2035 as being critical provided Switzerland is linked to its electricity neighbours – even with the future phasing out of nuclear energy.[2] An electricity agreement with the EU is an important prerequisite, however. Bottlenecks also need to be eradicated, for example by means of a grid expansion, and there is need for renewal of the transmission grid.

In the absence of corresponding investments, Switzerland's supply security is not guaranteed.

Notes and References

1 Swiss Federal Office of Energy 2018; Modelling the Swiss Gas Market in a European Context. https://www.aramis.admin.ch/Default.aspx?DocumentID=46726&Load=true
2 Federal Office of Energy 2018; Modellierung der System Adequacy in der Schweiz im Bereich Strom. https://www.bfe.admin.ch/bfe/en/home/supply/electricity-supply/security-of-electricity-supplies.html

Digitalisation # Energy storage

2.10. Wanted: new systems and new components

The challenges arising from the inclusion of decentralised energy providers have a spatial and temporal dimension. The spatial dimension affects the local distribution grids as well as the national transmission grid. The temporal dimension ranges from seconds to seasonal fluctuations. The basic principle here is that quick and smaller-scale fluctuations are managed at a local level to the greatest extent possible, while slow and larger fluctuations are handled at a national level in the transmission grid. Swiss hydropower plants will play an important role here as they can operate flexibly.[1] However, an important question is whether the balancing capacity of hydropower will still be sufficient in the case of a massive expansion of photovoltaics. In future, seasonal fluctuations will also be balanced out via exchanges with other countries – at least in part.

In principle, the challenges can be tackled with two different approaches. Some problems can be resolved with new control systems, while others require the development or improvement of new physical grid components such as transformers and storage solutions.

The fluctuations to be expected in the electricity grid with respect to the provision of power can be absorbed in part with local energy storage devices[2] – primarily batteries. In most cases, these do not have a large capacity and are therefore best suited to smaller-scale intermediate storage over shorter periods of time. The batteries of electric cars also offer storage capacity that can be utilised for the adjustment of tariff and taxation systems. However, other systems are required for multi-day and seasonal storage: compressed air reservoirs, pumped-storage plants and power-to-gas (P2G). Heat can be stored in underground storage tanks, as is planned, for example, in the energy concept of the ETH Hönggerberg campus.[3]

Notes and References

1 Synthesis on “hydropower and market”

2 New storage technologies for the balancing of daily fluctuations

3 ETH Real Estate 2017; The energy of tomorrow, ETH Zurich

2.11. Multi-stage synthesis process

This synthesis on the main topic of “Energy Networks” was created as part of a multi-stage process. In October 2016, when the researchers were still in the middle of performing their project work, they exchanged information on their research questions, methods and solutions in order to identify interdependencies and potential synergies. Half a year later, the researchers met with representatives from associations, federal offices, cantons and relevant NGOs in order to find out more about the expectations placed on the research results and their dissemination.

On the basis of these findings, the Steering Committees of the NRP “Energy” developed a synthesis concept for each of the six main topics. An initial draft of the synthesis on “Energy Networks” was developed on the basis of this concept by Göran Andersson, scrutinised within the Steering Committees of the NRP “Energy” and edited by a science journalist.

In June 2019, an echo group comprising nine specialists from the worlds of administration and business came together in order to reflect on and assess the draft synthesis (see “Publication details”). They also evaluated the recommendations with a view to their impact and feasibility. Following further revisions and additions, the synthesis was approved in September 2019 by the Steering Committees of the NRP “Energy”.

3. Three focus areas

The findings of the research projects on the topic of “energy grids” were assigned to three focus areas:

1. Integration of prosumers and decentralised energy stores
2. Supply security
3. Energy as an overall system

3.1. Integration of prosumers and decentralised energy stores

Energy Strategy 2050 plans for new renewable energy sources to provide more energy – primarily PV and wind power plants. How much energy will be generated by these new providers is dependent on the weather. The sector has a great deal of experience with fluctuating electricity consumption and also has efficient methods at its disposal for very precisely predicting consumption levels. However, the new decentralised energy providers are giving rise to new uncertainties – especially as the existing methods are primarily applicable to larger geographic areas and local conditions are more difficult to forecast. An additional challenge is the fact that the number of stakeholders is massively increasing.

Market # Energy storage # Decentralisation

3.1.1. Greater flexibility required

For the stable operation of an electricity grid, the consumption and generation of electricity must always be in equilibrium, i.e. the grid frequency must be constantly kept within narrow limits. In order to balance out the unavoidable demand fluctuations in an electricity grid, control power and reserve capacities are required that can be made available in a traditional, centrally fed electricity system from easily controllable power plants (e.g. storage plants, gas turbine power plants).

In the future energy system, it is not only demand that will fluctuate, but rather also electricity provision. This is because the output of wind and solar plants is greatly dependent on the time of day and point in the year as well as the weather. While the daily and seasonal fluctuations can be forecast relatively well, the weather influences are linked to uncertainties. The decentralised electricity providers also influence the voltages of the distribution grid. Traditionally, distribution grids have been dimensioned in such a way that only consumers are linked. Decentralised providers will change the voltage profile and there may be increasing grid voltages. These can be avoided, for example, by turning off PV systems or with the help of regulating transformers. These new conditions in the electricity grid call for additional flexibility.

There is now a broad range of flexibility measures in the electricity grid, including[1]:

- Electricity imports and exports
- Supraregional compensation via the national electricity grid
- Needs-based operation of easy-to-regulate power plants (e.g. bioenergy plants, storage power plants)
- Expansion of decentralised storage capacities (e.g. e-vehicles, battery storage systems, compressed air reservoirs, power-to-gas)
- Connecting and disconnecting of flexible electricity consumers (load management)

- Temporary disconnecting of renewable energy providers (feed-in management)

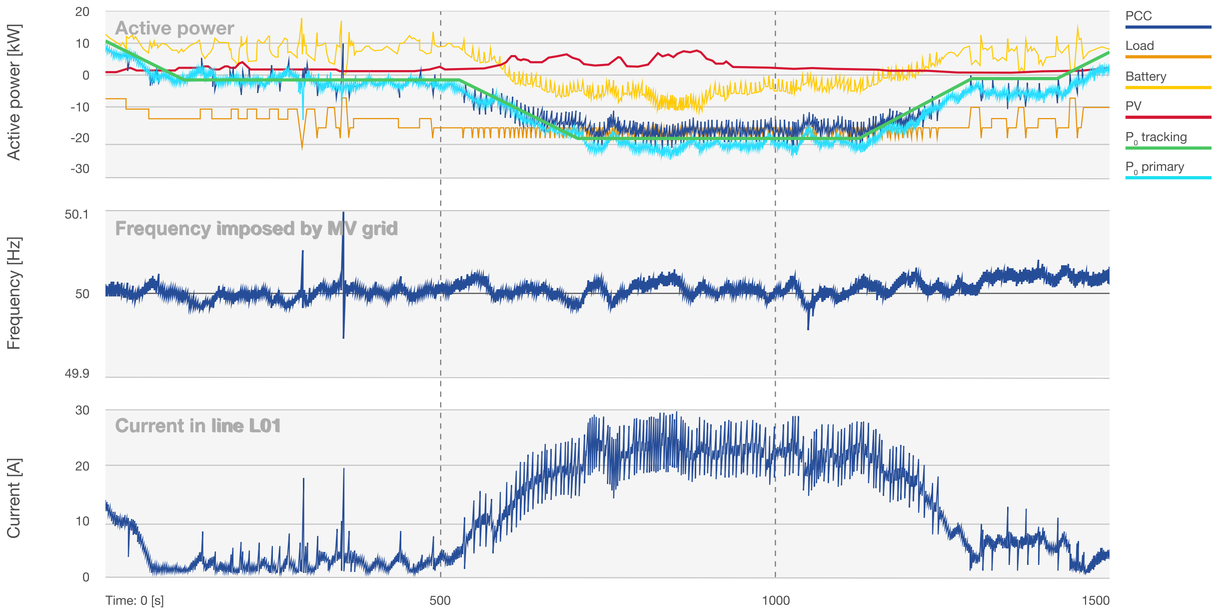
These flexibility measures come at a cost. The optimal package of measures from a technical and economic perspective must always be put together in a manner that is appropriate for the situation at hand.

Notes and References

1 Renewable Energy Agency (2019); Flexibilität für den Strommarkt der Zukunft, Renews Spezial, No. 87, Berlin

Digitalisation # Supply security # Decentralisation

3.1.2. Prototype of a new control system for distribution grids



The top diagram shows measurements from the operation of the EPFL microgrid with the developed control system. The green curve is the target value of the agreed power exchange with the national system (Swissgrid), the light blue curve (PCC) is the actual exchange. The difference between these two curves is the contribution of the microgrid to frequency control: if the frequency – the middle diagram – is lower or higher than 50 Hz, the exchange changes to ensure the frequency is stabilised. The transformer between the microgrid and the national grid is the bottleneck of this system; this is typical for systems with many PV plants and charging stations for electric cars. The bottom diagram shows that the control system can keep the exchange flow below the maximum value. To achieve this, the flexibility of the system components is utilised.
Source: Le Boudec report, Fig. 2. p. 6, Fig. A

How can challenges relating to the integration of prosumers and decentralised energy stores be addressed at a distribution grid level? Answers to this question are provided by the project “Real-time control of power flows”[1]. The objective of the project was to develop a new control system for the real-time regulation of future distribution grids and microgrids.[2]

The proposed control system, which integrates consumers, PV, batteries, fuel cells, heat pumps and charging stations for electric cars, is based on software agents. A prototype was tested on the campus of the EPF Lausanne.

The “Multiport Energy Gateway” (MEG) was developed and tested for the interface between the energy storage solution and the grid. The MEG is a new power electronic converter that enables the quick regulation of energy flows.

The key benefits of the new control system relative to traditional methods are as follows:

- The system makes possible the optimal regulation of energy storage solutions, load management and decentralised energy sources.
- The system ensures that all grid limits are adhered to. This enables decentralised providers and charging stations for electronic cars to be massively expanded without grid reinforcements.
- A distribution grid with this control system can offer the transmission grid system services such as frequency control.

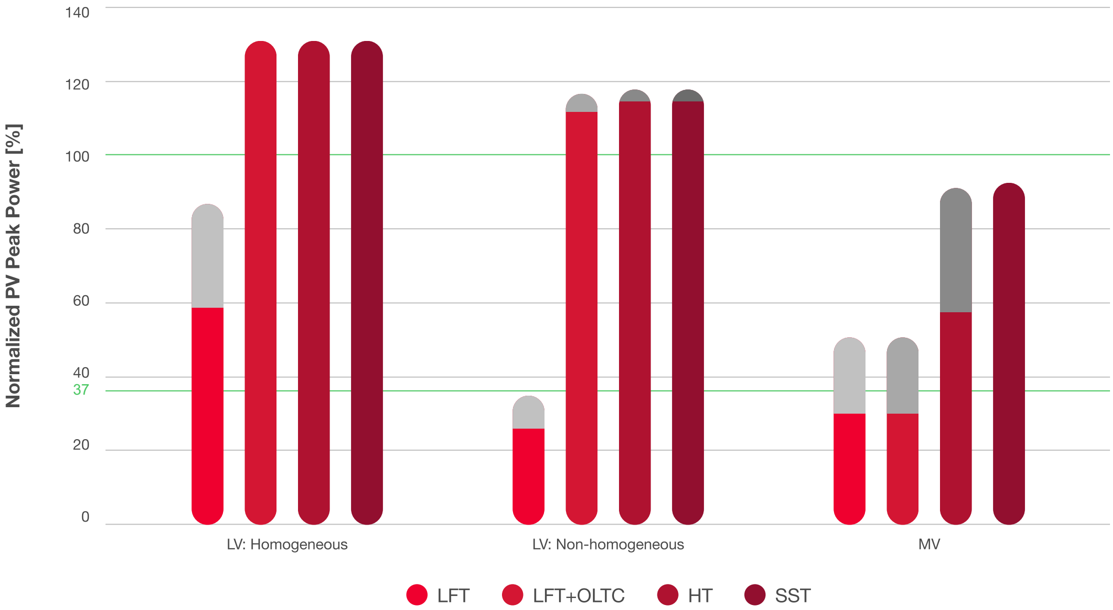
Notes and References

1 Project “Real-time control of power flows”

2 A microgrid is a grid that can function without an electrical connection to the national grid. A microgrid can typically be a village or a residential district. Normally, the microgrid is connected to the national grid. However, stand-alone operation is also possible.

Photovoltaics

3.1.3. New transformers for voltage regulation



The capacity of the medium-voltage grid (MV) is decisive for this case. 37 % corresponds to the scenario under Energy Strategy 2050 and 100 % corresponds to the Swissolar scenario often used in PV studies. LFT = transformer without the ability to regulate voltage. LFT-OLTC, HT, SST = transformers with the ability to regulate voltage. Grey: Influence of reactive power compensation. *Source: Project "SiC solid-state transformer in the grid"*

The joint project "SwiSS solid-state SiC transformer"[1] looked at new transformer concepts and their impact on the feeding in of electricity from PV into the grid. Focus was primarily placed on investigating the importance of voltage regulation. The project "SiC solid-state transformer"[2] examined various transformer types at grid level 6 of the distribution grid. A traditional transformer that cannot regulate voltage was compared with three types of transformer that can. The results are presented in the diagram below. It can be seen that the PV feed-in can be increased with the transformers with voltage regulation capacity – LFT+OLTC, HT and SST.

The comparison between the microgrid project "Real-time control of power flows" of the EPF Lausanne[3] [4] and this project is interesting. For the EPFL microgrid, the bottleneck problem was resolved with the control system, while a hardware solution was used here. It is not possible to make a general statement about which solution is better. Many factors have to be taken into account in both cases based on the specific situation at hand.

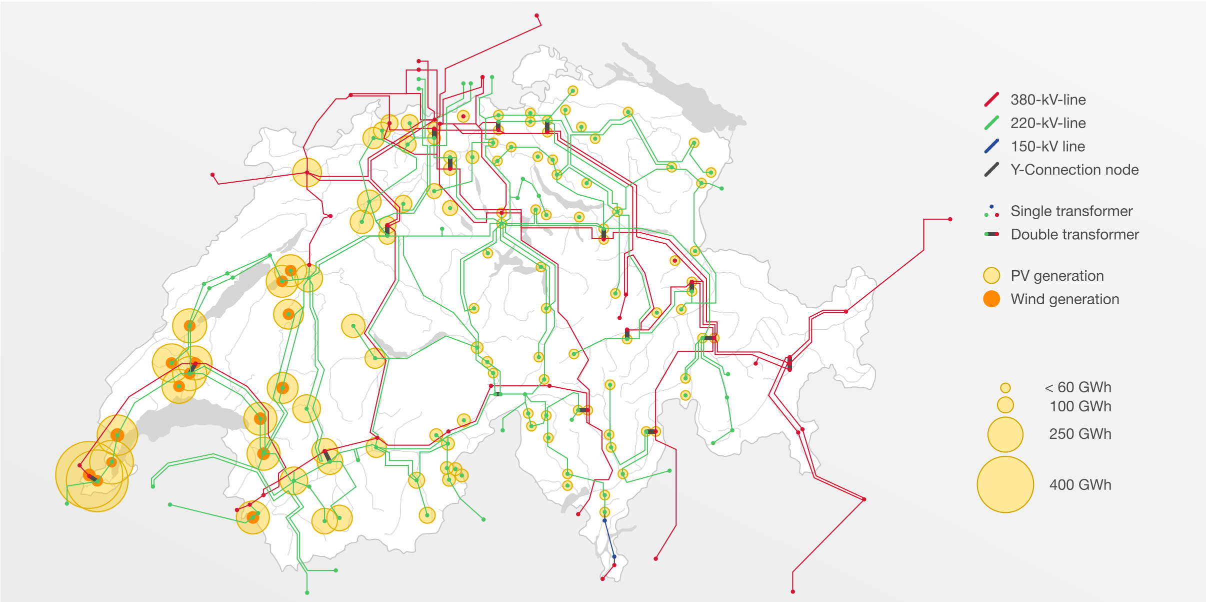
Notes and References

1 Project "SwiSS solid-state SiC transformer"

2 Project “SiC solid-state transformer”
3 Project “Real-time control of power flows”
4 Prototype of a new control system

Market

3.1.4. Make future energy flows manageable



PV and wind energy generation for the scenario "2050 Renewable Support". *Source: Project "Future energy infrastructure"*

A fundamental question is how the Swiss transmission grid can manage the major challenges posed by PV and wind energy. The project "Future energy infrastructure" [1] addressed this issue. The following was investigated:

- Topographic and economic conditions for PV and wind energy in Switzerland
- The potential of renewable energy in Europe using weather-based simulations
- The flexibility of the Swiss electricity system with respect to balancing for renewable energy
- The reliability of the Swiss transmission grid

Various scenarios were analysed using a new simulation model. It is part of a bigger model that also models electricity markets.

The key conclusions drawn were as follows:

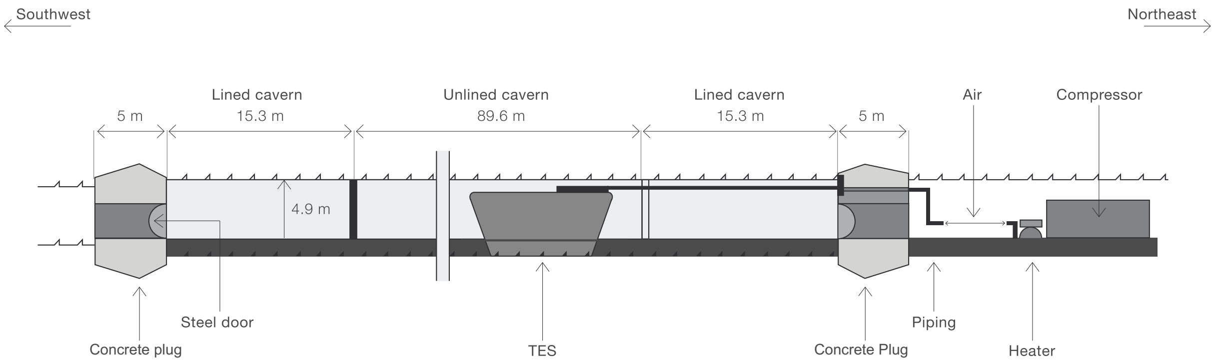
- PV is more cost-efficient in Switzerland than wind power.
- The flexibility of the current Swiss hydropower sector enables 19 GW of PV and 0.55 GW of wind energy to be integrated in the grid, which meets the objectives of Energy Strategy 2050.
- With the planned expansion, the Swiss transmission grid can manage the future energy flows.

Notes and References

1 Project "Future energy infrastructure"

Battery # Energy storage

3.1.5. New storage technologies for the balancing of daily fluctuations



Scheme of a compressed air reservoir. *Source: Project "Optimising compressed air storage"*

Pumped-storage power plants will in future also play a significant role in balancing out fluctuations. However, their expansion potential is limited. New storage technologies are therefore required. There are already batteries in the electricity grids. These can be small – in the kW range, often with small PV plants – or large – in the MW range for the provision of grid support and flexibility. In future, the batteries of electric vehicles will offer further storage potential.

At present, most batteries are lithium-ion based. New battery technologies that are not yet commercially available could be better suited, however.

The project "New materials for future batteries"[1] investigated the fundamental requirements for lithium-air and lithium-water batteries and new materials that lead to increased energy densities for such batteries. At the same time, the project shows the theoretical and practical difficulties associated with the commercial production of these batteries. Should the development of battery types bring about lower prices and improved technical characteristics, an even greater distribution of batteries can be anticipated.

As part of the project "Power storage via adiabatic air compression[2], the compressed air storage technology was developed further – with the objective of increasing its efficiency to up to 75 %. An integrated thermal storage device prevents the heat energy generated during the compression of the air from being wasted. On the basis of a pilot system, the new thermal storage device and the overall system were tested; models for all sub-systems were developed and simulations were conducted with an output of 100 MW and a capacity of 500

MWh.

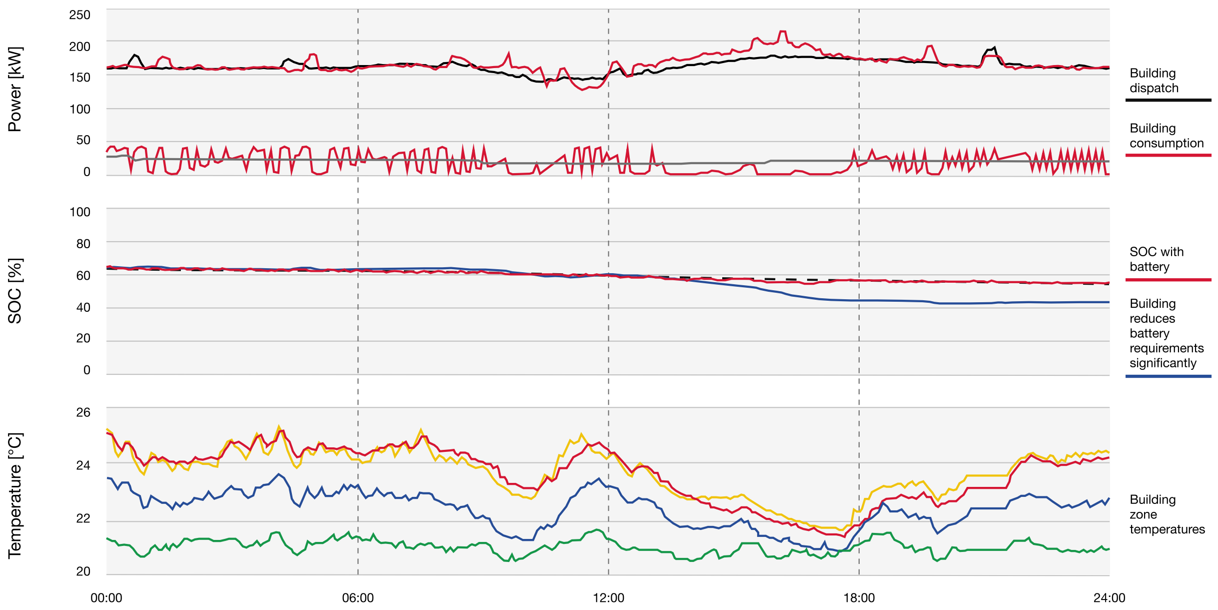
Compressed air reservoirs are especially interesting for Switzerland as local underground conditions are predominantly good for the construction of caverns. They can represent a viable alternative to large battery installations and pumped-storage power plants. The project also revealed that the environmental impact of a compressed air reservoir is lower than that of a pumped-storage power plant.

Notes and References

1 Project “New materials for compressed air storage”
2 Project “Electricity storage via adiabatic air compression”

Building # Battery # Energy storage

3.1.6. Buildings as thermal storage vessels



Operation of a combination comprising virtual building storage and an electric battery during the course of a day. This combination considerably reduces the requirements placed on the expensive electric battery. *Source: Project "Demand and storage in electricity networks"*

The thermal inertia of a building can be viewed as a virtual storage vessel that can be integrated in the overall system. Here, however, it must be taken into account that the time constants of the electric system are much smaller than those of buildings. A new control system[1] solves this problem – and also ensures that a building's temperate remains within the comfort zone.

The project "Demand and storage in electricity networks"[2] developed and tested methods for the utilisation of the thermal storage capacity of buildings. The system was tested as part of an EPF Lausanne pilot project. The virtual storage of a building was combined with an electric battery and using the developed control system the overall storage system was regulated in such a way that rapid fluctuations are balanced out with the electric battery and slow fluctuations are offset with the virtual building storage.

The overall storage system can offset the fluctuations in the test system's PV provision and consumption in such a way that the test system behaves like a deterministic electrical load. With the virtual building storage, the required battery capacity can be reduced by up to 80 %.

Notes and References

1 Prototype of a new control system for distribution grids

2 Project "Demand and storage in electricity networks"

Market   # Digitalisation

3.1.7. Integration of prosumers and decentralised energy stores: need for action

The research work conducted as part of the NRP Energy on the "integration of prosumers and decentralised energy stores" revealed the following areas where action is needed:

- **Flexibility**. Flexibility is becoming ever more important with respect to energy supply. Possibilities are required that permit energy consumption and provision to be controlled technically on the basis of system requirements and through the provision of economic incentives. For the electricity grid, a sufficiently large flexibility reserve is especially important. This is because the consumption and provision of electric energy must be in step at all times. The electricity grid therefore requires short-term flexibility for daily fluctuations and long-term flexibility for seasonal variations. The more PV and wind energy that is integrated in the grid, the greater the need for flexibility. The project "Future energy infrastructure"[1] shows that Swiss hydropower makes possible the integration of a considerable share of PV and wind power in the grid. Where there are additional sources of flexibility – batteries, compressed air reservoirs, load management, etc. – it is possible to make better use of hydropower. Generally speaking, increasing flexibility means that the provider of flexibility cannot operate its own system at an optimal level from a technical or economic perspective – flexibility therefore has a price.

- **Digitalisation**. The current energy supply system does not work without control and monitoring systems. Their introduction was a prerequisite for ensuring the high level of efficiency and reliability provided by the energy supply system. As shown by projects of the NRP Energy, many future challenges can be managed with new principles and algorithms for regulation and monitoring purposes. The general development and research progress being made in the area of ICT will presumably lead to new energy supply solutions. This will likely affect almost all stakeholders and all areas of the energy system. However, the increasing level of digitalisation also poses new, major challenges:

- Cyber risks have to be managed with a view to supply security.
- The use of relevant data for the operation of the grid must remain assured – while also ensuring that data protection legislation is adhered to.

Notes and References

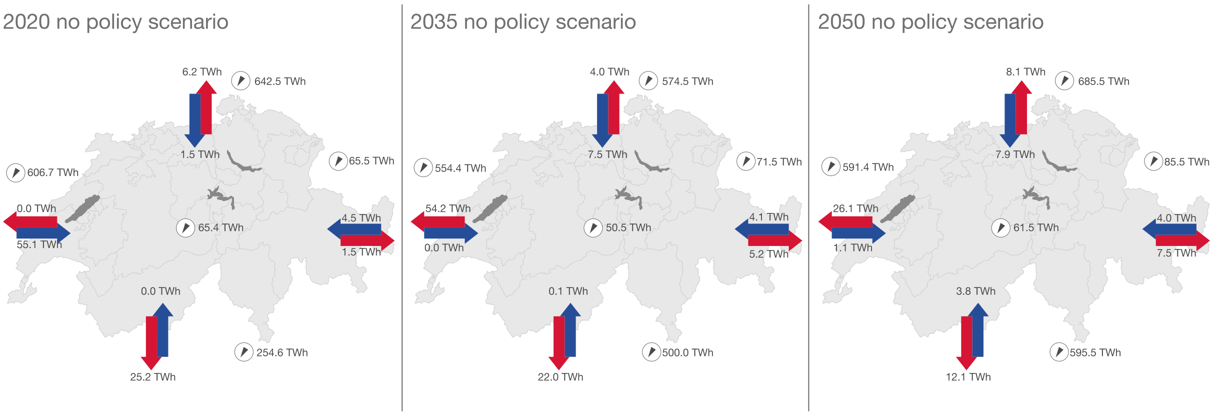
1 Project "Future energy infrastructure"

3.2. Supply security

If the new stakeholders are to be integrated into the overall energy system in an efficient and reliable manner, new electricity grid operating principles, in particular, will be required that take account of the characteristics of the new players. Only in this way will the grid's stability and optimal operations remain assured. A further important requirement for supply security is the involvement of Switzerland in the European electricity market.

Europe / EU # Photovoltaics

3.2.1. The expanded transmission grid will suffice



Switzerland's annual electricity imports and exports and electricity generation per country for 2020, 2035 and 2050 under the "no policy" scenario. *Source: Project "Future energy infrastructure"*

The energy integration of Switzerland in Europe primarily takes place via the electricity and gas grid. In order to ensure local supply security, the transmission grid must have an adequate capacity – at its interfaces with neighbouring countries and within Switzerland itself.

To this end, the project "Future energy infrastructures"[1] developed models and examined Switzerland's supply security under two scenarios.

The **"no policy" scenario** assumes that there are no guidelines with respect to the promotion of renewable energy. Results:

- In 2020, electricity exports and imports will be in equilibrium over the course of a year, with net imports during the winter. In 2050, Switzerland will generally import electricity over the entire year.
- There will be no increase in the load on the lines – it will even fall. This is for the following reasons:
  - The new lines planned by Swissgrid will improve the situation.
  - An expansion of electricity generation in Italy will reduce the need for electricity transit through Switzerland.

The importing and exporting of electricity will therefore not overload the transmission grid.

The **“Renewable support” scenario** assumes that renewable energy will receive political and economic support. Results:

- In 2050, PV plants will generate more than 11 TWh each year. This energy cannot be fully fed into the grid. However, due to grid restrictions, only 8.9 GWh must be disconnected – this is less than 0.1 % of the PV plants’ total production.

In both scenarios, the lines are subjected to very similar loads. The reason for this is that the PV systems are distributed throughout Switzerland, with small feed-ins in many locations and some larger feed-ins in French-speaking Switzerland.

Conclusion: following the planned expansion, the Swiss transmission grid can manage the electricity flows within Switzerland as well as the export and import flows under both scenarios. This is also shown by the project “Trade-offs in switching to renewable electricity”.[2] Nevertheless, it must always be remembered that without the planned expansion of the transmission grid, supply security is not guaranteed.

Notes and References

1 Project “Future energy infrastructure”
2 Project “Trade-offs in switching to renewable electricity”

Energy grids # Acceptance

3.2.2. Hybrid lines have many benefits

At present, all lines in Switzerland are based on the globally dominant principle of alternating current. Worldwide, direct current accounts for a share of only a few percent, but this share is increasing. This is because direct current technology offers some key benefits. Direct current lines are, for example, more compact and enable more energy to be transmitted in a given line route. With cheaper and more efficient power electronics, high-voltage direct current (HVDC) transmission has been significantly expanded at an international level. A major benefit of HVDC transmission is that the transmitted power and the voltage can be controlled based on requirements – this is not possible with alternating current lines.

If high-voltage pylons support two or more alternating current lines, one of these can be converted into a direct current line. This creates a so-called hybrid line with a greater overall capacity that enables the technical benefits of alternating and direct current to be utilised in equal measure.

The combination of alternating current and direct current on the same high-voltage pylon, however, leads to new technical challenges, for example with respect to corona discharges – electric discharges into the air – and the associated noise. The project “Hybrid overhead power lines for Switzerland”[1] looked at these challenges and developed theoretical and experimental solutions for hybrid lines. The investigations were verified in a test system. The project “Acceptance of renewable energy”[2] looked at the inherent acceptance problems associated with overhead power lines.

The test system for hybrid lines in Däniken.

Source: Project "Hybrid overhead power lines for Switzerland"

The projects also examined system aspects for Switzerland. Two different line corridors were examined with an optimal power flow (OPF) calculation. Important results include:

- The controllability of the hybrid line can ease the burden on pure alternating current lines and therefore increase the grid's capacity.
- The load on the grids with 220 kV and 110 kV can also be relieved. This means that more capacity is available for energy generated on a decentralised basis.
- Despite slightly higher energy losses, the operating costs can be reduced as local energy producers can be better integrated. However, the investment costs must also be taken into account in a comparison of overall costs.

Notes and References

1 Project "Hybrid overhead power lines for Switzerland"
2 Project "Acceptance of renewable energy"

Energy grids   # Acceptance

3.2.3. Underground lines enjoy greater acceptance

The question of acceptance is always an issue with respect to power lines. The project "Acceptance of renewable energy"[1] shows that communication is decisive for new power line projects. Negative information in the lead up to line constructions of any kind leads to a considerable decline in acceptance. It is also more important to minimise the negative effects – noise and the visual impact – than to maximise technical efficiency. If a line is cabled and buried, levels of acceptance are greater than when a new overhead power line is created – but the costs are also higher and there are technical challenges, especially in the case of longer cables. Reactive power compensation is required for voltage regulation, for example.

However, the "Electricity grid strategy", which has been in place since 2017, requires underground lines for new construction projects and expansion projects provided the additional costs of an underground line provide sufficient environmental and health benefits relative to an overhead power line.[2]

Notes and References

1 Project "Acceptance of renewable energy"
2 Expansion of the electricity grid

Regulation # Europe / EU

3.2.4. Supply security: need for action

The research work conducted on “supply security” revealed the following areas where action is needed:

- **Grid expansion**. The transmission grid must have sufficient capacities in order to be able to manage the energy flows as per Energy Strategy 2050. This relates to both connections with neighbouring countries and domestic lines. To this end, the planned grid expansions and the required maintenance measures must be performed in good time. The grid expansion plans must also be updated on an ongoing basis in order to take account of new developments. New technologies such as hybrid lines can offer important benefits.
- **Regulation and integration**. In addition to technical aspects, regulatory and political issues are also significant. The synthesis on “market conditions and regulation”[1] looks at this topic in detail. The complementary studies “Switzerland and EU energy policy”[2] and “Europeanisation of the Swiss energy system”[3] also looked at the question of how the Swiss energy system can now be integrated in the European system and how this involvement will develop.

Notes and References

1 Synthesis on “market conditions and regulation”
2 Project “Switzerland and EU energy policy”
3 Project “The European electricity market: staying away will be expensive but will also open up room for manoeuvre”

3.3. Energy as an overall system

The decentralised provision of energy from PV and wind plants gives rise to an array of challenges with respect to the stability of the electricity supply system due to daily and seasonal fluctuations. Decentralised multi-energy hub systems offer a promising solution here. These utilise the interplay between various energy sources such as solar energy, heat, natural gas and hydrogen and combine renewable and conventional energy sources, conversion technologies and storage technologies.

Sector coupling

3.3.1. Sector coupling as a key success factor

Until now, the energy system has been planned, developed and operated in a highly fragmented manner: the individual energy sources of electricity, gas and heat have had their own organisations, financing models and legislation. Energy consumers including households, manufacturing industry and service providers, as well as passenger and transport companies, have also been largely isolated, with some even operating their own energy supply. It therefore comes as no surprise that in the past no joint development projects were launched and synergies were not exploited.

The future energy system needs to overcome this narrow-minded thinking. This is because the objectives of Energy Strategy 2050 can only be achieved if all stakeholders work together and pull in the same direction. The strategic focus areas are grid convergence and sector coupling. The term grid convergence originates from the communications sector and means the early coordination of various grids, including the gas and district heating grids. This leads to streamlined and economical grids in which each energy source optimally exploits its strengths. The primary objective is sector coupling, which involves the linking of various energy sources and energy consumers (i.e. sectors). This may, for example, see the linking up of electricity and heat prosumers in the residential and employment sectors with motorised private transport (e-vehicles) and energy storage. For such constructs, power-to-gas solutions and bioenergy plants can play a key role.

Experts are in agreement that the objectives of Energy Strategy 2050 cannot be achieved without wide-ranging sector coupling. This is because it is expected to make a substantial contribution to grid stability, the economic viability and the supply security of the future energy system. This is provided energy consumers are organised carefully and intelligently in order to bring this about. As part of the NRP “Energy”, a great deal of attention was paid to decentralised multi-energy hub systems as an especially attractive case of sector coupling.

Sector coupling # Decentralisation

3.3.2. Decentralised multi-energy hub systems (DMES)

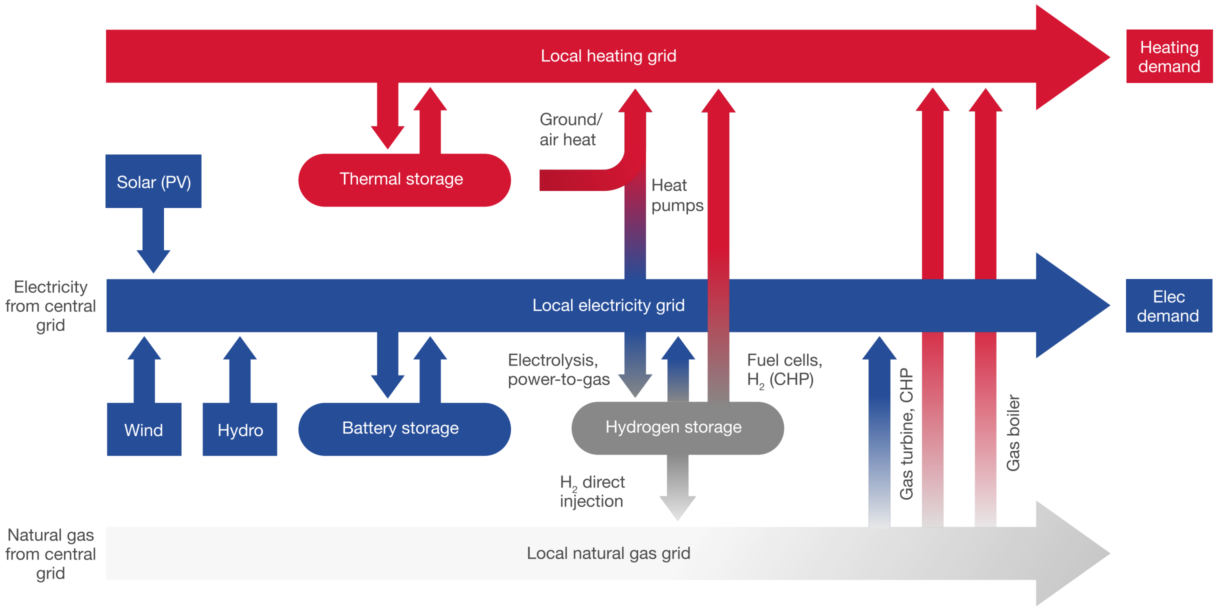


Illustration of performance of a DMES. *Source: Project "Multi-energy hub systems'*

The decentralised provision of energy from PV and wind plants gives rise to an array of challenges with respect to the stability of the electricity supply system due to daily and seasonal fluctuations. Decentralised multi-energy hub systems, an especially auspicious form of sector coupling, offer a promising solution here.[1 2] These utilise the interplay between various energy sources such as solar energy, heat, natural gas and hydrogen and combine renewable and conventional energy sources, conversion technologies and storage technologies.

If the objective is to optimise the entire energy system with respect to various criteria such as efficiency, flexibility, costs and emissions, the most important energy sources have to be taken into account: electricity, gas and heat. In order to model the interactions between these energy sources and thus between local electricity, gas and heating grids, the concept of decentralised multi-energy hub systems (DMES) – so-called energy hubs – was developed.

A DMES can, for example, be a settlement, a district, a large hospital or an industrial facility. DMES can be linked together, meaning that a system of DMES can also be investigated.

Notes and References

1 Synthesis on "buildings and settlements"
2 Project "Sustainable decentralised power generation"

Decentralisation

3.3.3. Analysis of decentralised multi-energy hub systems at two locations

The project “Multi-energy hub systems”[1] developed a comprehensive and integrated method for the optimal design, operation, regulation and evaluation of decentralised multi-energy hub systems (DMES). The method was used in order to investigate optimal DMES at two locations: the village of Zernez in the canton of Graubünden and the Zurich urban district of Altstetten. Optimal technology portfolios and regulation strategies were developed in order to ensure electricity and heating requirements were met with the lowest possible operating costs and CO_2 emissions and various scenarios were examined with respect to the use of renewable energy.

The most important results were as follows[2]:

- In order for realistic and practical statements to be made about optimal technology portfolios, better and more precise mathematical models are required for micro combined heat and power devices (mCHP), fuel cells and power-to-gas. Such models were developed in the project.
- Robust and distributed control algorithms are key for reliable operations and customer satisfaction.
- The decisive parameters for the optimisation of the technology portfolio and control algorithms are the availability and type of renewable energy sources as well as the needs of consumers. Each DMES must be designed on an individual basis.

Building stock and solar radiation in the example cases of Zernez and Zurich-Altstetten.

Source: Project “Multi-energy hub systems”

Notes and References

1 Project “Multi-energy hub systems”

2 Synthesis on “buildings and settlements”

Battery   # CO2 / greenhouse gases

3.3.4. Combination of short- and long-term storage

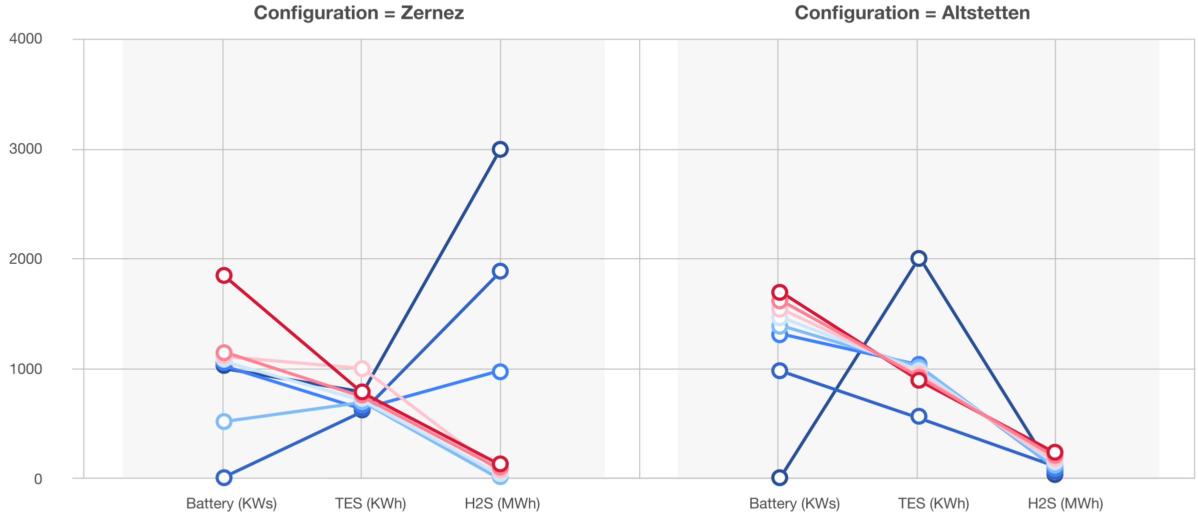


Figure 5. Size of the considered storage technologies (battery, hot water thermal storage H_2 storage) for Zernez (left-hand-side) and Altstetten (right-hand-side) for a multi-objective optimisation minimising total annual cost (red tones) and CO_2 emissions (blue tones).

Storage combinations for the example cases of Zernez and Zurich-Altstetten. *Source: Project "Sustainable decentralised power generation"*

How can short- and long-term storage solutions be optimally combined in a DMES? The project "Sustainable decentralised power generation"[1] addressed this question. The investigation showed that seasonal storage solutions such as power-to-gas (P2G) are effective if many decentralised renewable energy sources are available in the observed system. These storage devices can also make a great contribution to reducing CO_2 emissions. In the diagram, the sizes of various storage technologies are entered – batteries, thermal storage devices (TES) and hydrogen storage devices (H2S). The diagram on the left shows the situation for Zernez, while the diagram on the right shows the situation for Altstetten.

The way in which short- and long-term storage technologies can be optimally combined depends on the objectives of the optimisation. A cost optimisation leads to a storage combination that is visualised with the red curve. A minimisation of CO_2 emissions leads to the combination of the dark-blue curve. Optimisation scenarios situated between these two extremes are shown with the curves in the other shades of blue.

The storage combinations developed for the respective optimisation scenarios are therefore system-dependent. If renewable energy sources are available to a sufficient degree – as is the case in Zernez – the optimal storage combinations per scenario are very different to those for locations such as Altstetten with relatively little potential for renewable energy. The results shown in the figure apply to Zernez and Altstetten. Other combinations may be optimal in different systems. However, the method developed in the project is of a general nature and can be applied to any system.

Notes and References

1 Project "Sustainable decentralised power generation"

Sector coupling # Digitalisation # Decentralisation

3.3.5. Energy as an overall system: need for action

The research work conducted on “energy as an overall system” revealed the following areas where action is needed:

- **Distribution grids and the transmission grid**. Until now, the distribution grids have been more or less static with daily and seasonal fluctuations in energy consumption. With decentralised energy providers such as PV and with local energy storage solutions and local control systems, the situation is changing radically: the distribution grid is becoming active and controllable. As operator of the transmission grid, Swissgrid can exploit the controllability of the distribution grids in order to optimise the operation of its grid with respect to efficiency, supply security and stability, for example. To make this possible, more measurements within the grid and greater communication between the involved stakeholders are required. The ICT needed to this end is becoming ever more affordable and increasingly efficient.

- **Sector coupling**. Various energy sources are suitable for different purposes, meaning that the energy sources have traditionally been viewed separately. Until now, this has not led to major losses from a technical or economic perspective. However, new technologies such as fuel cells are leading to the greater linking of energy sources – and are making the integration of energy sources, for example in a decentralised multi-energy hub system (DMES), logical.

4. Eight steps towards the energy future

In the vast majority of cases, energy is transported from the energy providers to energy consumers via energy grids. Changes to these grids affect a broad range of stakeholder groups: private households and businesses, energy providers and distributors, public authorities and politicians.

However, the following recommendations are aimed exclusively as those stakeholders who have a direct influence on the future shaping of energy grids. These include, in particular:

- Private households and businesses as energy consumers
- Energy suppliers, divided into energy providers and energy distributors
- Politicians (federal government, cantons, municipalities)

Furthermore, recommendations have primarily been formulated that can be derived from the research work conducted in the NRP “Energy” and that are also relevant with a view to the transformation of the energy system.

Digitalisation # Households # Businesses

4.1. Make processes, plants and devices more flexible!

In the electricity grid, stability is essential. If more energy is fed into the grid from volatile new renewable energy sources, greater flexibility is required as a counterbalance, for example in the form of storage solutions.

Energy Strategy 2050 envisages the integration of new renewable energy sources such as PV and wind power in the energy system. This will require greater flexibility – only this can ensure grid stability. Flexibility sources can be found both on the side of energy providers and energy consumers. These sources should be utilised in a cost-efficient and technology-neutral manner. Digitalisation will make a major contribution here, for example in the area of the Internet of Things or smart meters.

Flexibility among energy consumers will be achieved through the use of load management – for example with respect to heat pumps and electric vehicles. Without them being made more flexible, considerable grid expansion in the distribution grid would be required. For the procurement of production systems (businesses) as well as household, ICT and other appliances (households and businesses) and for the introduction of business processes, it must therefore be ensured that these are either themselves designed for flexible energy procurement or can be operated flexibly via an intelligent control system.

Investment   # Energy suppliers

4.2. Utilise the synergies of various energy sources!

The various energy grids can no longer be viewed individually – they are part of an overall system that offers a variety of synergies.

Electricity, gas and heating grid operators clarify which advantages and disadvantages would emerge from the overall optimisation of all energy grids at a regional level. The synergies of sector coupling need to be utilised on a systematic basis. The projects of the NRP “Energy” show that an integral overall view of the energy system is beneficial for energy grids. In order to be able to optimise the energy system in its entirety, the parochial thinking of the individual energy sources and consumers needs to be put to an end and replaced with an overall strategy. Existing grid-specific regulations also need to be reconsidered integrally.

Digitalisation # Energy suppliers

4.3. Push ahead quickly with digitalisation!

In order to achieve the objectives of Energy Strategy 2050, the potential offered by digitalisation needs to be exploited.

Digitalisation is a requirement for the cost-efficient and market-based involvement of decentralised energy providers as well as efficient grid operation including storage solutions.

In the distribution grids, in particular, the introduction of new control systems can improve the integration of many decentralised energy sources and increase flexibility. Load management for energy consumers is to play an important role in these systems aimed at ensuring a stable grid. The technologies and processes required to this end are based on large quantities of data, complicated algorithms and machine learning – on digitalisation. Without these tools, which have only been utilised in some cases until now, it will not be possible to control – and therefore manage – the ever more complex energy system.

Digitalisation # Energy suppliers # Politics (federal government, canton, municipality)

4.4. Make secure use of digitalisation!

The digitalisation of our energy system entails risks that need to be identified in good time and managed effectively.

The risks of digitalisation affect all stakeholders. These unsettle many players within the system and can hinder the implementation of Energy Strategy 2050. The following risks are particular areas of focus:

- Risks of cyber attacks that pose a massive threat to supply security.
- Risks for privacy and personal freedom due to inadequate data protection. With a view to the transformation of the energy system, energy distributors have a great responsibility to take the fears and uncertainties of energy consumers seriously and to implement effective, trust-building measures aimed at managing the risks and ensuring data protection.

Market # Investment # Energy suppliers

4.5. Create and sell flexibility!

In the electricity grid, in particular, flexibility is a valuable resource – and must be remunerated at market prices.

The higher the number of energy providers with fluctuating power feed-ins, the greater the need for flexibility. The question arises as to how flexibility should be created, traded and remunerated in future – for example in line with the current regulations regarding the provision of frequency control. The linking of energy systems provides significant potential for flexibility. Energy storage devices can also increase flexibility. During the planning of new plants and the conversion of existing ones, energy providers attach special importance to the creation of additional flexibility. They develop new business models in order to be able to offer flexibility as a service.

Regulation   # Digitalisation   # Investment   # Politics (federal government, canton, municipality)

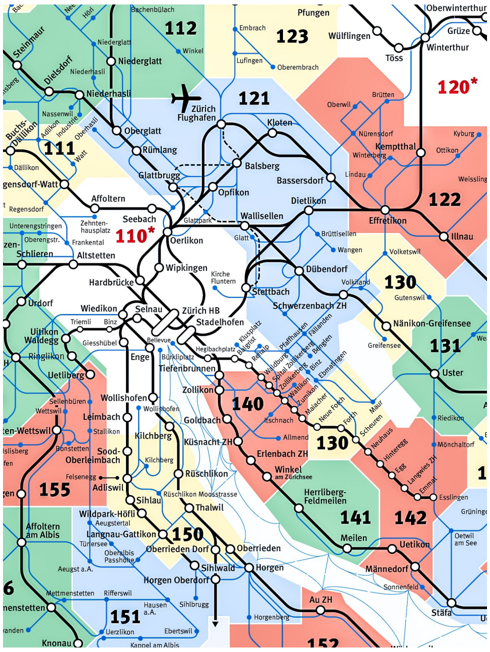
4.6. Create framework conditions with room for manoeuvre!

The energy system requires stable framework conditions – as well as room for manoeuvre.

Together with the modalities of the European energy system and the prevailing economic and financial conditions, Switzerland's regulations form the framework conditions for the development of the energy system. They define the technical and economic room for manoeuvre of all stakeholders and can either be supportive or obstructive depending on the shape they take. Politicians need to create stable framework conditions with adequate room for manoeuvre. The framework conditions need to be stable because investments in the physical infrastructure of the energy system have a time horizon of several decades. And they require room for manoeuvre because technology is developing quickly, digitalisation is providing scope for new innovations and economic conditions are also changing.

Tariff # Investment # Politics (federal government, canton, municipality)

4.7. Create effective tariffs and fees!



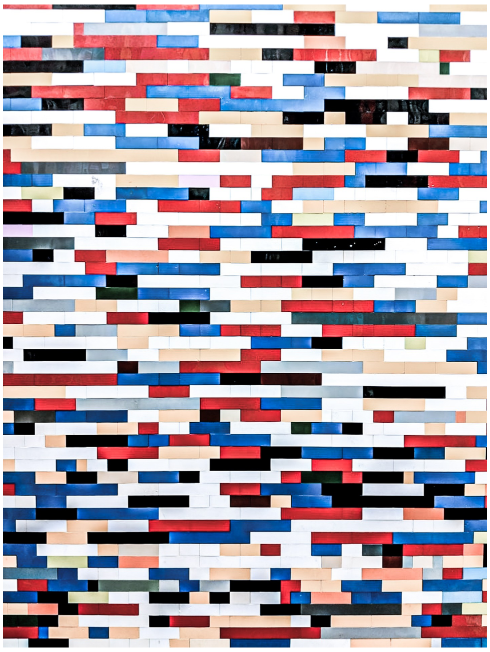
Source: Zürcher Verkehrsverbund ZVV

Flexibility and the user-pays principle can be promoted with dynamic tariff models.

Flexibility is not only of key importance for the technical side of energy grids. Fees and tariffs also need to be structured flexibly in order to ensure that developments are not hindered. Grid tariffs and fees are shaped in a way that ensures there is sufficient spatial and temporal flexibility and that this is remunerated appropriately from an economic perspective. At the same time, fairness, the user-pays principle and the impact on the environment need to be taken into account and weighed up against each other. Tariffs, data availability and billing systems need to be modernised to this end.

Regulation # Investment # Europe / EU # Politics (federal government, canton, municipality)

4.8. Push ahead with integration in the European energy system!



When it comes to energy matters, Switzerland is not an island, but rather linked to Europe. The integration of Switzerland in Europe must therefore be clarified quickly.

Especially with respect to the energy system, Switzerland is greatly dependent on developments in Europe as a whole. It needs to play as active a role as possible in shaping these developments. Cross-border electricity trading, in particular, is of key significance for grid stability and long-term supply security. An electricity agreement with Europe is an essential requirement here.