Research for Switzerland's energy future

Résumé of the National Research Programme «Energy»

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Under the title «National Research Programme Energy» the results of the two National Research Programmes «Energy Turnaround» (NRP 70) and «Managing Energy Consumption» (NRP 71) are amalgamated and presented together.

This résumé of the National Research Programme «Energy» outlines the results from the total of 103 research projects and four complementary studies, as well as the six thematic syntheses and four joint syntheses, conducted under the programme. On the basis of these findings, it goes on to draw conclusions and make recommendations. It is a scientific contribution to the process of opinion formation, to political and specialist debate as well as to the planning of strategies and measures necessary for the transformation of the energy system against the backdrop of Switzerland's Energy Strategy 2050.

The programme résumé was created as part of a multi-stage process. Numerous experts have provided text contributions that have been consolidated and edited by a science journalist. An echo group comprising eight specialists from the worlds of administration and practice have reflected on the draft document and assessed it from their perspective. The Steering Committees have further developed and approved the programme résumé. This text is the responsibility of the authors. Their assessments and recommendations for action do not necessarily reflect those of the echo group, the experts who have made text contributions, the research teams or the Swiss National Science Foundation.

Further information on all of the NRP «Energy» research projects named below can be found on the web portal at www.nrp-energy.ch.

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With the decision to revise the Energy Act and thus to implement Energy Strategy 2050, Switzerland's voters opted in favour of the phasing out of nuclear energy. In doing so, they have initiated the transformation of the Swiss energy system – a task of extraordinary importance. With the National Research Programmes «Energy Turnaround» (NRP 70) and «Managing Energy Consumption» (NRP 71) – summarised under the title NRP «Energy» – the Federal Council has tasked the Swiss National Science Foundation with obtaining scientific findings and developing innovative approaches aimed at supporting this transformation and with formulating corresponding recommendations.

In more than 100 research projects, the NRP «Energy» has generated a wide range of findings and innovations. These projects make important and pioneering contributions with respect to both basic developments and practical implementation. The research work has produced findings in numerous areas that are extremely valuable from both a social and political perspective. For example, it is made very clear that the transformation of the energy system remains a task for society as a whole that can only be tackled with a combination of technical and social innovation. While research and innovation may open doors and pave the way for further progress, it is the individual stakeholders and politicians acting on behalf of society that will decide whether the proposed solutions are adequate and acceptable in everyday life – and are viable.

The individual pieces of research work looked at the challenges posed by the transformation from very different perspectives. The fact that some statements are in part contradictory demonstrates the conflicting aims encountered during the transformation process. In the syntheses on the main topics, the NRP «Energy» has weighed up these considerations and, to the extent the research results allow, consolidated them to provide an overall picture. Despite its breadth and the variety of topics covered, the programme is unable to provide an all-encompassing answer to the wide-ranging challenges posed by the transformation of the energy system. Key areas such as mobility and the role of digitalisation could not be addressed in the required depth. Moreover, in the context of the climate debate, energy policy is developing dynamically. Recommendations for which it might be virtually impossible to reach political consensus today could gain majority support in the near future.

With their work, the researchers of the NRP «Energy» have provided numerous pieces of the puzzle that will need to be solved if the major task of transforming the energy system is to be completed successfully. The syntheses on the main topics have put these pieces in order and prepared them for implementation. All information on the individual research projects and the syntheses can be found on the specially created web portal at www.nrp-energy.ch.

The stakeholders discussed in this summary – namely energy providers, private households, businesses, homeowners, investors, public administrative bodies, associations, NGOs, voters and politicians – are now responsible for picking up the arranged pieces of the puzzle and pushing ahead with the transformation of the energy system.

Prof. Dr. Hans-Rudolf Schalcher
President of the Steering
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President of the Steering
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Against the backdrop of the implementation of Energy Strategy 2050 and the next stages of climate policy, in 2012 the Swiss Federal Council launched the National Research Programmes «Energy Turnaround» (NRP 70) and «Managing Energy Consumption» (NRP 71). Whereas NRP 70 primarily dealt with technological issues, while taking economic aspects into account, NRP 71 specifically addressed the socioeconomic and regulatory aspects of transforming the energy system. The results of both research programmes are consolidated under the title «National Research Programme Energy» (NRP «Energy»).

The combined total of more than 100 research projects of the NRP «Energy» have generated a wealth of individual results. Some of these projects have promoted or created technological innovation, while others have analysed the economic or social environment. Various projects have dealt with technical issues as well as economic and socio-economic aspects of transforming the energy system and have investigated the sustainability of innovation. In section 2, this résumé provides an overview of the challenges posed in light of the transformation of the Swiss energy system initiated in accordance with Energy Strategy 2050. Section 3 presents the action areas associated with the transformation as well as the approaches developed by the NRP «Energy». Section 4 highlights those aspects that, in the view of the NRP «Energy», appear to be especially relevant for the transformation. On this basis, recommendations are formulated in section 5. With the suggested approaches and recommendations, the résumé is especially aimed at those key stakeholders who, to a considerable extent, shape the energy system and who can thus also influence its development.

The findings generated from the NRP «Energy» once again underline the fact that socio-political aspects are just as important for the transformation of the energy system as technical issues; they provide the key for realising the technical solutions. To ensure that individual people become active in their various roles, they must be aware of the specific possible courses of action in each case and must also be in a position to implement them.

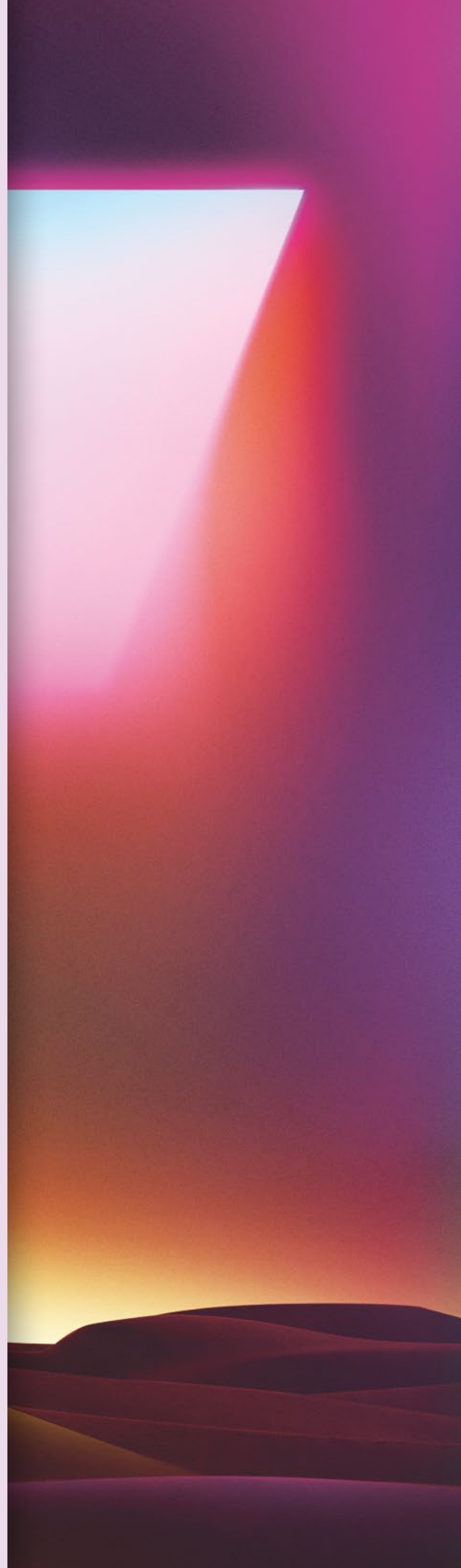
Mobility and Switzerland's building stock offer great potential for the realisation of Energy Strategy 2050. In the area of mobility, contributions can be expected, in particular, from energy-efficient vehicles. However, new fuels, innovative mobility concepts and voluntary behavioural changes will also play a role. Still today, the country's building stock offers great opportunities for improving efficiency and using renewable energy for electricity and heating provision. It also provides substantial space, as yet underutilised, for the installation of photovoltaic systems. If the building stock is renovated much quicker and more extensively, this will allow it to achieve or even exceed the expected contribution to the transformation of the energy system.

Hydropower will in future continue to play a key role for the Swiss energy system. If it is to continue to perform this function, it must be given greater attention. While hydropower offers potential to boost efficiency, the possibilities for expansion remain severely limited due to economic and environmental considerations.

However, the central finding of the NRP «Energy» is that legislation as a whole does not provide the support required for the transformation. Furthermore, the implementation of the legal mandates will require greater coordination of state representatives at, and between, all government levels. Finally, cities and municipalities have room for manoeuvre that many could use more actively to push ahead with the transformation.

1

Overview and recommendations



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Magazine «E&» | Energy & Fiction, Illustration: Magdiel Lopez

15 recommendations

1 – Promote energy efficiency with targeted regulation and push ahead with the expansion of renewable energy!

Many of the technologies that are required for the transformation of the energy system are already available. However, especially with respect to buildings and the mobility sector, if their employment remains on a voluntary basis, they will not be used sufficiently. In order to achieve the set objectives, regulatory interventions are therefore also required alongside market-economic incentives. Various preliminary policy decisions that have been taken recently are moving in the right direction.

2 – Create incentives to save energy with flexible and dynamic electricity tariffs, reward targets and information!

Energy distributors should develop and use flexible and dynamic electricity tariff models that create an incentive to reduce electricity consumption and energy costs. The acceptance of such tariff models increases when combined with bonus elements that reward the achievement of saving objectives.

3 – Support the expansion of renewable energy with a comprehensive and effective CO_2 incentive tax!

Steering measures are more effective and cost-efficient than promotion measures. A CO_2 incentive tax on fossil energy sources is therefore especially suitable for advancing the transformation of the energy system.

4 – Implement CO_2-free urban logistics by 2050!

If urban agglomerations are supplied in a CO_2-free manner, 7% of the corresponding efficiency objectives of Energy Strategy 2050 and around 9% of the targeted reduction in greenhouse gas emissions could be achieved. Cantons, cities and municipalities should therefore create corresponding framework conditions and work together with logistical stakeholders.

5 – Implement decentralised multi-energy hub systems (DMES)!

Decentralised multi-energy hub systems (DMES) allow for the highly efficient use of energy provided on a decentralised basis. To enable these systems to be implemented, energy provision and supply must be viewed as a whole at both a local and regional level. Self-organisation and state regulation should complement each other in the best way possible. The municipalities as well as the federal government and the cantons need to perform the preliminary planning and legal work.

6 – Focus hydropower on its stabilising function within the energy system!

The new types of renewable energy are faced with the problem that production and use often do not coincide. Hydropower fulfils a key role in this context: it stabilises the supply system and ensures the technical supply security of the Swiss energy system. This function can also serve as a basis for financial compensation.

7 – Base water fees on earnings!

In 2024, a new solution has to be approved for the water fee. It should be based on income and thus reflect the market price and production costs. The new solution must also take account of the interests of mountain areas. For these areas, water fees are far more important from an economic perspective than they are for electricity producers.

8 – Adjust residual flow regimes in line with environmental needs!

At present, the Waters Protection Act is not being adequately implemented with a view to meeting ecological goals. The targeted level of biodiversity in river sections beneath dams is not being achieved. The cantons should therefore implement the legislation in a way that enables residual flow management to accomplish the ecological objectives. Corresponding measures require more water and reduce electricity production.

9 – Create optimal conditions for financing models in which the population can participate!

Financial involvement in infrastructure investments for renewable energy creates identification. Locally based organisations such as associations, cooperatives and neighbourhood organisations create acceptance and help to advance the expansion of renewable energy.

10 – Actively involve the population in the planning of infrastructure projects from the outset!

Active participation strengthens identification and promotes acceptance. Project initiators should therefore make the planning processes for projects in the area of renewable energy participatory from the outset.

11 – Communicate knowledge – focussed on target groups and in a neutral way!

Measures aimed at communicating knowledge and information must use innovatively designed strategies to tap into the different levels of knowledge and various motivations of different population groups. The federal government, cantonal, city and municipal administrations, as well as associations and businesses, must provide information on the functioning of technologies and steering mechanisms. They must also communicate convincingly that a large part of the available energy-efficiency potential can be achieved without sacrifice or a loss of comfort: greater energy efficiency does not mean less comfort.

12 – Increase the accountability of associations!

Associations interact closely with their members and possess sector-specific knowledge that can advance the transformation of the energy system. They should also use their important role in the political decision-making process to win over their members and gain their support for jointly developed solutions!

13 – Motivate cities and municipalities to utilise their room for manoeuvre in the energy sector more actively!

Cities and municipalities have a wide range of possibilities for helping to shape the transformation of the energy system. This can be seen in their role as building owners as well as proprietors and operators of public plants and businesses and in their function as political players and supporters of local initiatives. They can become active – not only in the energy sector – at a planning, organisational and communicative level.

14 – Quickly clarify the relationship between Switzerland and the EU in the interest of assuring supply security in the electricity sector!

Switzerland uses electricity imports to offset the marked seasonal fluctuations in electricity production from hydropower plants. Relations with the EU and thus the European energy markets will in future determine how and at what cost this compensation can be assured. In the absence of an electricity agreement, the associated costs will be much higher.

15 – Develop a federal concept for the transformation of the energy system!

Poorly coordinated or even uncoordinated planning and approval processes put the brakes on many energy infrastructure projects. The federal government, cantons and municipalities should therefore create a reliable basis in the form of a jointly developed concept in order to reconcile the interests of the various government levels and break down barriers.

Against the backdrop of the implementation of Energy Strategy 2050 and the next stages of climate policy, the Swiss Federal Council launched in July 2012 the National Research Programmes «Energy Turnaround» (NRP 70) and «Managing Energy Consumption» (NRP 71) and entrusted the Swiss National Science Foundation (SNSF) with their implementation. Above all, this mandate expected a foundation on which to develop the second set of measures of Energy Strategy 2050. Whereas NRP 70 primarily dealt with technological issues, while taking economic aspects into account, NRP 71 specifically addressed the socioeconomic and regulatory aspects of transforming the energy system. The results of both research programmes are consolidated under the title «National Research Programme Energy» (NRP «Energy»).

Among other influences, the NRP «Energy» is based on the federal government's «Coordinated Swiss Energy Research» report of 24 April 2012 and the associated dispatch. The Swiss Competence Centres for Energy Research (SCCER), which primarily aim to expand research capacity in the energy sector and thus deal with similar topics to the NRP «Energy», are also defined here. However, both research initiatives are fully complementary, meaning that there is no duplication.

NRP 70 has a financial framework of CHF 37 million, while the corresponding figure for NRP 71 is CHF 8 million. More than 350 project outlines were submitted in 2013. On the basis of a two-stage, international evaluation process, the Steering Committees selected 15 joint projects from these with a total of 62 sub-projects and 7 individual projects for NRP 70 and 19 individual projects for NRP 71. During the assessment of the projects, focus was placed on the expected contribution to the implementation of Energy Strategy 2050 and on their scientific quality. Over the course of the programme, four complementary studies were added to the total of 103 research projects. With their practical results, these serve to close important thematic gaps in the research portfolio of the NRP «Energy».

This résumé provides an overview of the challenges (section 2) posed in light of the transformation of the Swiss energy system. It presents the action areas associated with the transformation as well as the approaches developed by the NRP «Energy» (section 3). The résumé closes with those aspects that appear to be especially relevant for the transformation of the energy system from the perspective of the «NRP» Energy (section 4) and the recommendations derived on this basis (section 5). This résumé complements the six thematic syntheses[1] which provide an in-depth insight into the individual subject areas. With the suggested approaches and recommendations, the résumé is especially aimed at those key stakeholders who, to a considerable extent, shape the energy system and can thus influence its development.

1 The syntheses on the main topics of «Acceptance», «Buildings and Settlements», «Energy Networks», «Hydropower and Market», «Market Conditions and Regulation» and «Mobility Behaviour» of the NRP «Energy» are available in digital form on the web portal at www.nrp-energy.ch.

2

Transformation of the energy system

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Technologies shape the energy system, as do the political framework conditions and the stakeholders involved in the system. The challenges posed by the transformation of the energy system are correspondingly diverse.

Magazine «E&» | Energy & Networks, Illustration: Walkingframes Animation Studio

2.1 The future energy system

Both the current and future energy system (see figure 1) can be described as a complex socio-technical structure – complex because they are open, extremely dynamic and linked to numerous uncertainties and socio-technical because they have both a technical and social-organisational dimension. The technical dimension includes all technical elements of the energy infrastructure. This includes power plants, distribution grids, storage solutions and control systems as well as energy-consuming-devices such as household appliances, IT devices, production resources and modes or transport. The energy system's private and public stakeholders, who comprise, among others, the energy suppliers, households, businesses and politicians, are part of the social-organisational dimension.

Situated between these elements is a varied and dense network of relationships and flows. Among these flows, the actual energy flows (e.g. electricity, heat and gas), material flows (e.g. refuse, biomass), financial flows (e.g. fees, capital services and incentive taxes) and information flows especially stand out. The energy and material flows combine the technical elements, the financial flows and the data flows of the stakeholders. Further relationships arise from the processes that take place between the stakeholders (e.g. the political process which unfolds prior to the approval for the heightening of an existing dam wall) and the processes of cooperation and opinion-forming. There are also numerous system-relevant relationships that exist between the Swiss energy system and its environment. Nevertheless, the Swiss energy system will in future continue to rely on a strong network with Europe, which is, however, changing over time.

The future energy system will be more complex than at present. The number of stakeholders – and thus also the number of relationships – will increase, ever more energy will be provided on an irregular basis and system responsibility will be borne by more players. This complexity poses the stakeholders with the challenge of no longer planning and implementing measures for the development of energy system on an isolated basis, but rather as a coordinated package of measures that takes account of all impacts on the energy system as a whole, the environment, the economy and society.

2.2 Stakeholders and their room for manoeuvre

The NRP «Energy» looked intensively at the question of who has a significant influence on the energy system. A particularly interesting aspect was which stakeholders can put something in motion within a reasonable time. The core messages and recommendations based on the findings of the NRP «Energy» are aimed at these main stakeholders.

● **Energy suppliers** – The group of energy suppliers includes both energy providers, especially power plant operators and the operators of facilities for renewable energy, and energy distributors, who supply energy consumers with grid-bound energy sources.

Around 700 companies are active in the area of electricity distribution in Switzerland alone (SFOE 2019), with cantons and municipalities in some cases having significant stakes in these enterprises. Alongside the few major companies, there are also a large number of locally active city and municipal plants which, in addition to electricity distribution, are also responsible for gas distribution or operate district heating grids. Many of these companies are active both as energy providers and energy distributors. Their potential for influencing the transformation of the energy system is thus wide-ranging, meaning they can focus their investment activities and operating concepts accordingly. However, the energy distributors are also in close contact with the energy consumers

What is energy?

Energy cannot be created and cannot be lost. Colloquially, the term «energy consumption» therefore refers to the conversion of one energy-matter state into another, for example the burning of wood into smoke and ash, which releases heat as energy in a form that can be used for people or technology.

Nuclear fusion in the sun marks the starting point for almost all energy forms that can be used by people. During this process, two hydrogen atoms fuse to form helium, with their mass being reduced by Δm. According to Einstein's theory of general relativity, the released energy equals $E = \Delta mc^2$. The energy density is enormous: from one kilogram of hydrogen, the sun generates 100 billion times more energy than a gasoline engine does from one kilogram of petrol. A small part of the solar radiation generated through nuclear fusion reaches the Earth as light.

With the help of this solar radiation, living organisms create biomass that is locked in fossil energy sources such as crude oil and coal over long periods. In this case, the solar energy generated in the past is stored chemically and can be converted and made usable again by burning it with oxygen.

The chemical storage of solar energy can, however, take place more quickly and directly, for example via the recovery of biomass from waste or using fuels such as bioethanol and biodiesel. Many other renewable energy sources are also based on solar energy: the Earth's surface is warmed when reached by the solar radiation, bringing about a heat exchange with the atmosphere. The solar energy is thus the driving force behind all weather phenomena and together with the Earth's rotation causes wind, waves, rain, snow, lakes and rivers, which can all be used for the production of electricity. Photovoltaic modules convert up to a quarter of incoming solar radiation directly into electric energy. Solar radiation can, however, also heat liquids, for example in solar modules on building roofs or at solar thermal power plants.

Only a few energy sources are fully independent of the sun. Alongside nuclear energy, these include geothermal energy, the thermal energy stored in the Earth's interior, and tidal energy, which is based on the kinetic energy of the Earth and the Moon.

(households, businesses, building owners and landowners) and can influence their behaviour via their product development and pricing as well as via the provision of information.

The group of energy suppliers will in future grow ever closer together with the group of energy consumers. This is because the number of buildings that generate and consume energy at the same time is set to increase significantly. The development of decentralised multi-energy hub systems in connection with the linking of various energy sources (sector coupling, see section 3.3), for example through the integration of e-mobility or the linking of waste heat from industrial enterprises, is also seeing a reshuffling of the roles in the energy system. It remains difficult to predict the role of service providers that have to date operated outside the sector (e.g. Google and Amazon) and are now starting to position themselves on the energy markets thanks to web-based instruments, the use of «big data», «blockchain» and other digital technologies.

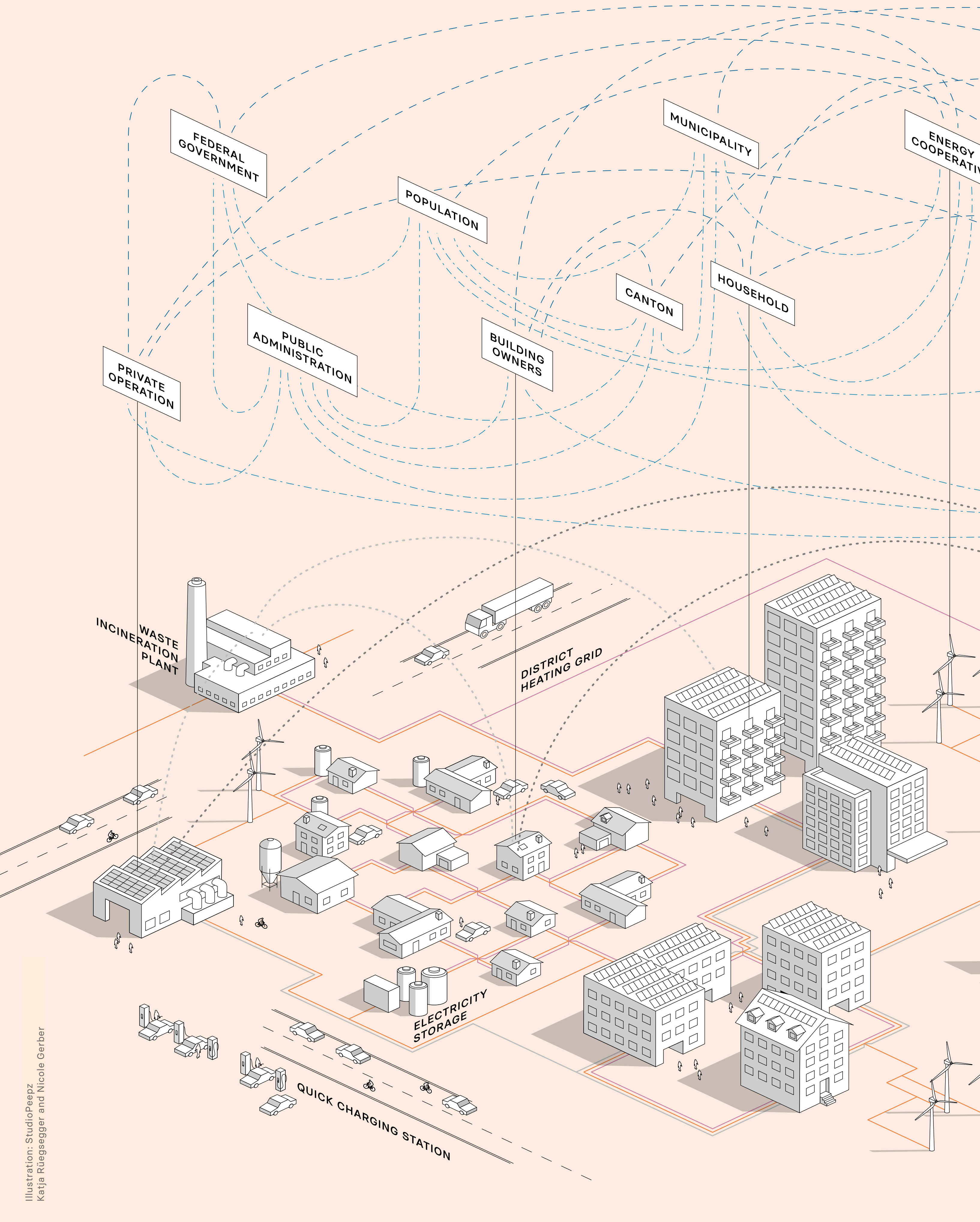
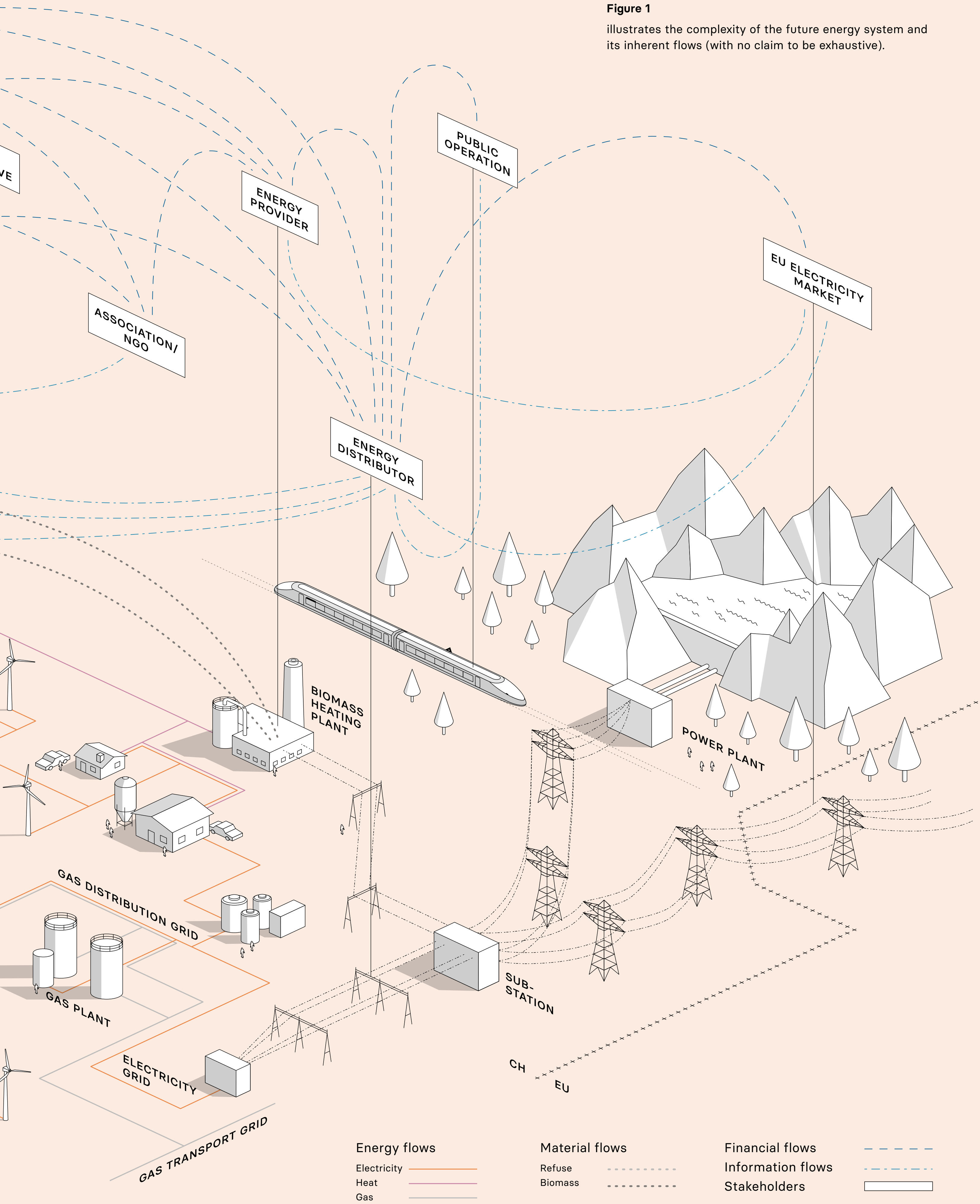
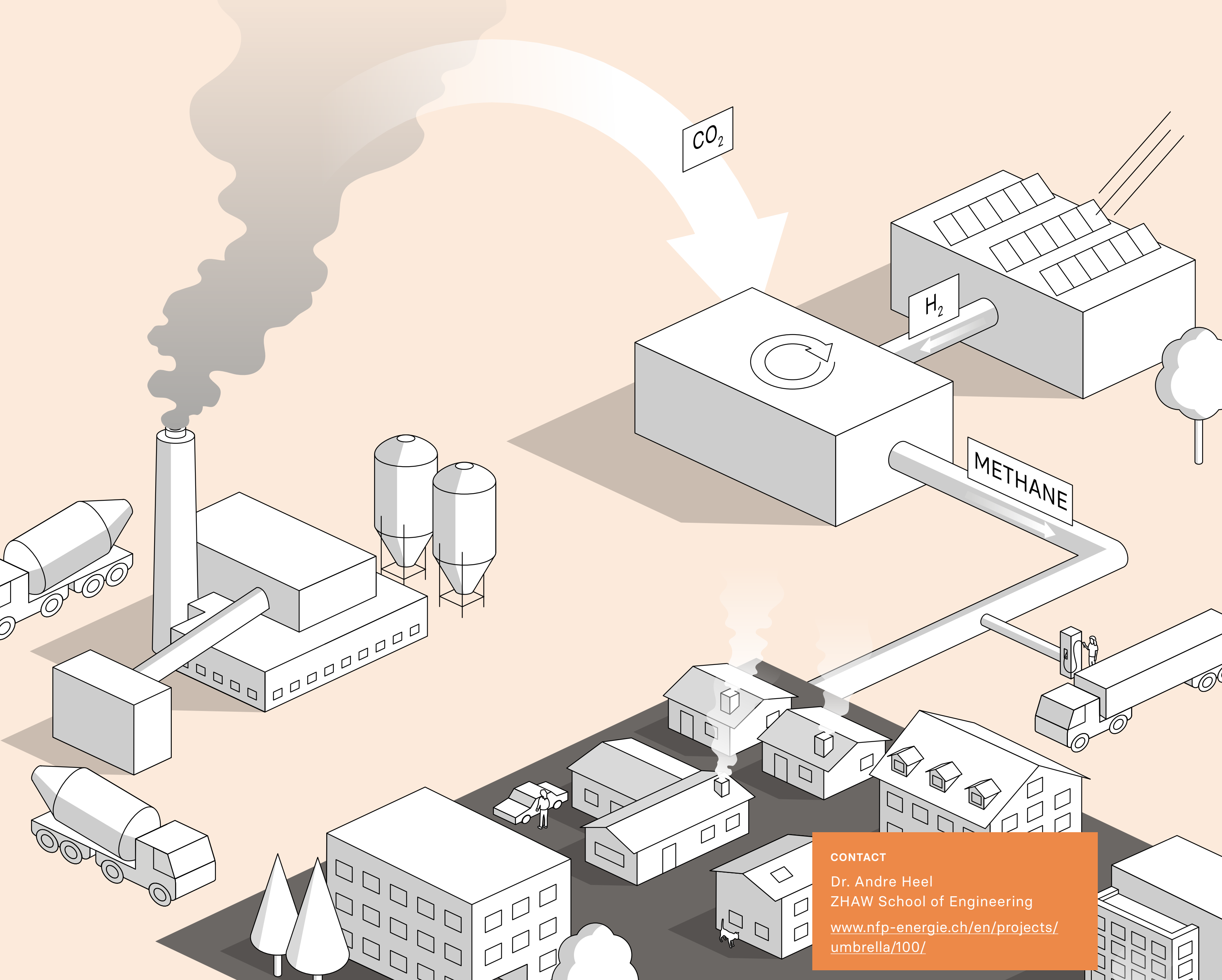


Illustration: StudioPeepz
Katja Rüegsegger and Nicole Gerber

Figure 1

illustrates the complexity of the future energy system and its inherent flows (with no claim to be exhaustive).





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PROJECT #CO_2/greenhouse gases #gas/hydrogen #methane/methanation

«Renewable fuels for electricity production»

In Switzerland, around 7% of CO_2 emissions occur in cement production. The research team investigated how the concentrated CO_2 could be converted into synthetic methane and how it would be possible to establish a new value chain. **The methanisation of the 2.5 million tonnes of CO_2 from Swiss cement production could replace one-third of all gas imports.** The team looked for more efficient, durable and cost-effective technologies for the corresponding conversion processes. The first process step, namely the production of hydrogen (H_2) through electrolysis, is the most expensive part of the value chain, accounting for around 90% of the costs. It is the reason why synthetic methane currently costs around three times more than fossil methane. In order to increase competitiveness, the solar electricity used for H_2 production and the corresponding electrolysis process must become cheaper or photoelectrochemical cells (PEC) need to be made more efficient. A sorption catalyst newly developed as part of the project enables the complete conversion of the CO_2 into methane, whereby the cost-intensive hydrogen is completely converted.

● **Private households** – Private households – people who live together in a home – are key stakeholders within the energy system. In 2017, there were 3.72 million private households (SFOE 2018) in Switzerland, around 6% more than in 2013. This number is growing further. One in every five homes is usually empty (SFOE 2018a). Many of these are heated nevertheless and supplied with hot water. As a consequence of demographic change, the number of people per household is declining. The energy reference area per person is therefore increasing.[2]

Private households consume 236 PJ (FSO 2018) per year and are responsible for 27.8% of Switzerland's energy consumption. This does not include their share of mobility. The energy consumption of private households is therefore higher than that of the industrial sector (18.5%). They also play a key role under Energy Strategy 2050: despite forecast population growth (+8.5% up to 2050), the energy consumption of private households is to be reduced to almost half (124 PJ) relative to today by 2050.

Private households are called on in various roles: in Switzerland, they act in their role as voters with wide-ranging rights of co-determination offered under direct democracy. They are also often faced with challenges in their position as the proprietors of owner-occupied properties. As the employees or even managers of businesses or public authorities, they can support the transformation of the energy system in yet another way. Above all, however, people are called on to take action in their private household as energy consumers.

● **Private and public enterprises** – Together, the approximately 145,000 industrial companies and about 457,000 service companies (as at 2016; SFOE 2018b) are Switzerland's largest energy consumers. These private and public enterprises consume energy for their operative and administrative processes as well as for the buildings in which they conduct their business activities. In 2017, the energy consumption of these businesses totalled 296.3 PJ or 35% of total energy consumption (industrial sector 18.5% and service sector 16.4%). This is slightly less than the consumption accounted for by transport (36.3%) but significantly more than that of private households (27.8%). Businesses primarily use electricity, followed by petroleum products, gas and wood. Around half of the energy from these sources is used for process heating, approximately a quarter for drive systems and about one-seventh for space heating (Prognos 2012).

With Energy Strategy 2050, businesses are confronted with major challenges: with a forecast increase in Switzerland's gross domestic product (GDP) of almost 30% by 2050 relative to today, they are to reduce their energy demands by almost 30% to 211 PJ by this date in accordance with the «New energy policy» scenario of Energy Strategy 2050.

● **Building owners** – In Switzerland, there are around 2.5 million private and public buildings (Rütter & Staub 2018) with a floorspace totalling about 940 million square metres and a building insurance value of approximately CHF 2,540 billion. Roughly 1.7 million of these buildings are residential properties. Of these, 89% of the buildings and 73% of residential properties are owned by private individuals (Rütter & Staub 2018). Out of the approximately 3.7 million apartments in Switzerland, around 57% are rented apartments (SFOE 2018e), with around half owned by private individuals. About a quarter are owned by institutional investors and 8% by cooperatives. Of the commercially used properties, 69% are owned by the businesses, while the remainder are occupied under long-term rental agreements. Only around one-seventh of the value of all properties – equating to CHF 350 billion – is owned by the public sector. Private individuals and businesses are thus the most important building owners in Switzerland.

The building stock accounts for a large share of Switzerland's energy consumption. In 2012, the final energy consumption of all buildings totalled 366,000 TJ (Prognos 2013) or 41.5% of total final energy consumption. This share exceeds the final energy consumption of the transport sector. Space heating is responsible for more than 70% of

2 [Energy reduction potentials of elderly people's households] buildings' final energy consumption. The energy reference area is therefore important as an indicator. In 2016, it totalled around 745 million square metres, with 67% of this area being accounted for by residential buildings, 21% by service buildings and 12% by industrial buildings (EnDK 2014).

In addition to the challenge of massively increasing the energy efficiency of their buildings, roofs, and more frequently also facades, are offering building owners the opportunity to install photovoltaic systems. In implementing such systems, they can assume various roles depending on whether they invest in photovoltaic systems themselves or assign these areas for use by third parties.

● **Outside creditors** – The transformation of the energy system requires considerable investment in infrastructure for the provision of renewable energy (hydropower, solar energy and wind energy) as well as for storage solutions and distribution systems. Given the service life of the plants and systems – especially in the case of hydropower – these are in some cases very long-term investments with a time horizon of several decades. With their investment decisions, the investors will play a substantial role in determining the shape that the transformation of the energy system takes and its dynamics.

Possible investors include institutional investors such as funds, pension funds and insurance companies. In connection with «energy efficiency» and with the expansion of renewable energy, a large number of small-scale investors (retail investors) are increasingly deciding about these investments. They are either participating through tailored investment offers or are organised, for example, in energy cooperatives or associations. Banks play a key role in all areas of energy investments, especially as intermediaries and outside creditors.

● **Public administration** – The federal government, cantonal, city and municipal administrations are central players in energy policy. They are responsible for the implementation of political requirements. In fulfilling this role, they use a wide range of instruments: regulative (technical standards for devices, buildings or vehicles; planning; building permits, etc.), incentive-based (granting subsidies and tax breaks; levying of incentive taxes, etc.) and persuasive (energy labels; awareness-raising campaigns, etc.) (Balthasar & Walker 2015). They thus have considerable potential for advancing the transformation of the energy system within their sphere of influence.

As the administrators and operators of public real estate portfolios, administrations also assume the role of building owners and businesses at all levels. And as the (co-)owners of energy companies, they also act as energy providers. Furthermore, they can significantly influence the development of mobility, for example by enforcing requirements concerning planning or placing orders for public transportation services.

● **Associations and other non-government organisations** – Professional associations, business groups and other organisations with a right to appeal, that seek to promote the interests of their sector and the common good, are committed to shaping, or want to influence, energy policy. These interest groups play an important role in the acceptance of energy-policy bills and projects among their members as well as during consultation procedures, parliamentary debates and referendum campaigns. Business organisations and environmental associations invariably also put up a fight during the political process or as part of approval procedures – for example in objecting to incentive taxes, in the case of the former, and in objecting to the construction of small hydropower plants, in the case of the latter. Professional associations organise the education and further training in their professional fields. Several of them (engineers, architects, electricians, etc.) perform regulatory tasks on the basis of their technical specialist knowledge and define technical standards and certification processes that are brought into legislation.

● Voters – In the direct democratic context of Switzerland, the population plays a more important role in its function as sovereign body than is the case in other countries where it is almost exclusively the government and parliament that make decisions on energy policy. In Switzerland, even small steps towards achieving the ultimate goal require the support of broad sections of the population. This applies to national, cantonal and communal referendums as well as to the resolutions passed by rural communities and at municipal meetings. The population's role as voters supplements their position as energy consumers as a second factor in their decision-making.

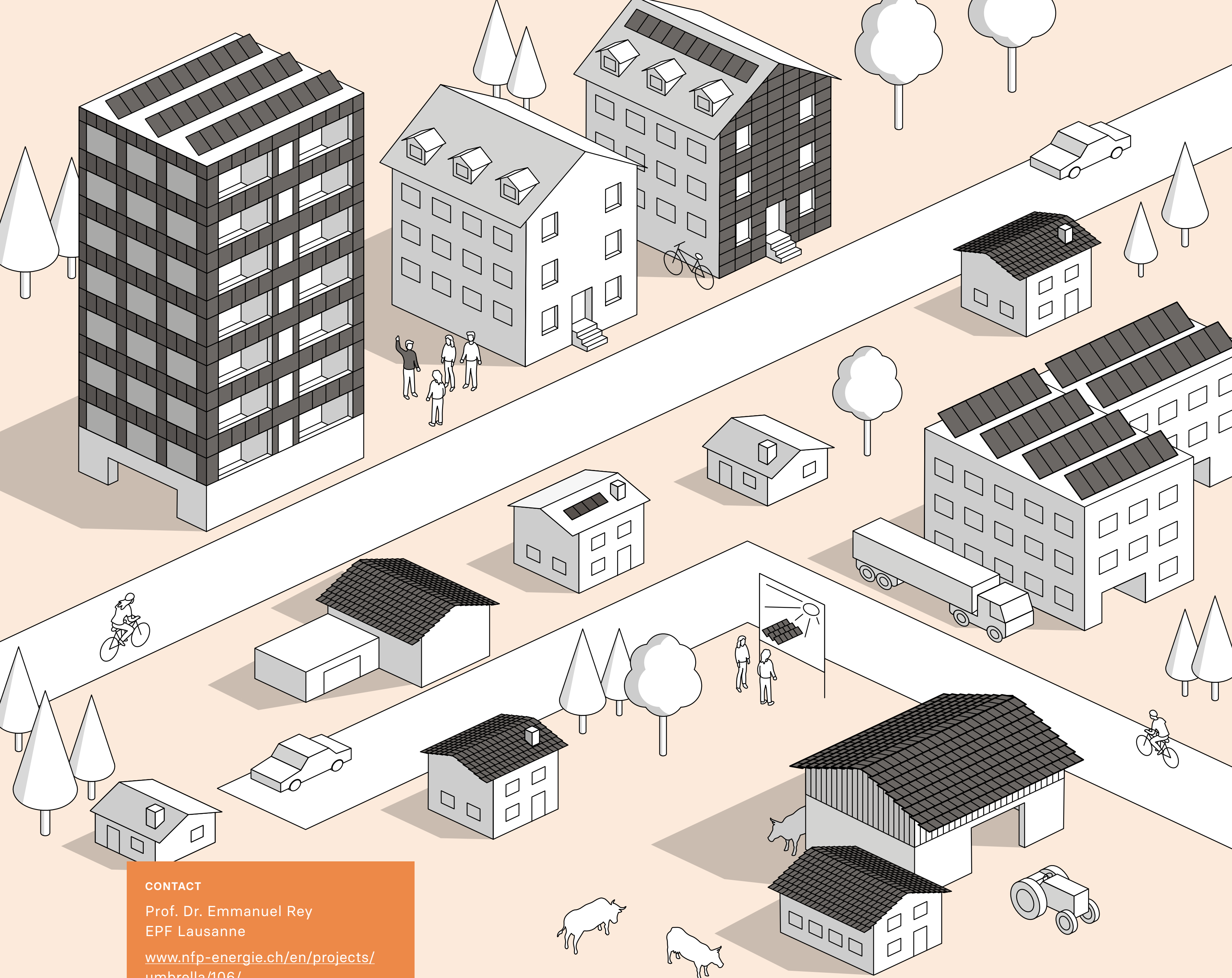
● Politicians (federal government, cantons, municipalities) – The political system in the form of the legislative, the executive and the voting population sets the framework conditions under which the transformation of the energy system can take place. The political realm not only determines energy policy in the strictest sense, but also makes decisions on other sector policies (environment, agriculture, regional policy, etc.) and on which interests are to be taken into account as part of the transformation process. Federal, cantonal and municipal policies also shape the planning and approval procedures that greatly influence the realisation of energy infrastructure projects. Furthermore, cantons and municipalities in some cases have significant stakes in energy supply companies and in this role determine, for example, their investment and price strategies.

2.3 Challenges of the transformation of the energy systems

With Energy Strategy 2050, an energy regime should emerge in Switzerland that, taking account of climate change, demographic developments and economic fluctuations, meets the set sustainability goals. It should enable the phasing out of nuclear energy and the expansion of renewable energy sources, while also making use of the creative scope provided by technical and market-based developments. In light of the requirements placed on the transformation process, questions and challenges have emerged in various areas.

Energy – a tough economic nut to crack?

Like all economic areas, the energy sector is shaped by costs, prices and markets. A transformation of the energy system will therefore be considerably influenced by economic drivers and relationships and will have corresponding economic consequences. With annual expenditure for energy of around CHF 25 billion (FSO 2019) and thus a share of gross domestic product (GDP) of 4% to 5%, the energy sector in Switzerland is a significant part of the economy. More than half of this spending results from the importing of fossil energy sources. However, its economic importance alone does not make the energy system a «tough economic nut to crack». Instead, it is its enormous complexity that is responsible here. This can be seen, for example, in the large number of energy-relevant decisions: for instance, around 4.6 million cars (FSO 2019) run on Switzerland's roads all have to be purchased, parked, moved and refuelled. For the provision of heating to around 1.7 million residential buildings (FSO 2018a), heating systems need to be purchased, maintained, refuelled or supplied with energy via other means. The more than 1,000 Swiss hydropower plants and approximately 700 energy suppliers (SFOE 2019) are a further example – these are closely linked to developments on the European electricity market and the corresponding decisions. Every change to the energy system therefore has implications for a large number of stakeholders, ranging from households and companies to government bodies, that in turn result in economic or operating costs.



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PROJECT #photovoltaics #buildings #acceptance

«Building-integrated photovoltaics»

Solar panels not only generate electricity. As building-integrated photovoltaic systems (BiPV), they can also be used as facade claddings. This not only reduces the consumption of fossil energy sources, but also saves material and electricity costs. However, building-integrated photovoltaic systems can only be found in isolated cases. The team of the project «Building-integrated photovoltaics» investigated how the current technical, economic and regulatory hurdles can be reduced – from the production stage right through to local implementation. In surveys conducted with architects and building owners, the researchers determined motives for the use of building-integrated photovoltaic systems as well as reasons for their rejection. **The project developed new strategies for architectural design in building renovations and new buildings,** combining the new generation of solar panels and innovative BiPV-based facade systems with architectural quality. The latter provide architects, installers, building owners and authorities with a range of solutions that take into account the characteristics and requirements of each building.

Energy – an environmental challenge?

The provision and use of energy is of great relevance from an environmental perspective. The associated processes and products make use of natural resources such as building materials, biomass – especially fossil resources including coal and crude oil – and space. They generate emissions such as CO_2, particulate matter or noise, have an impact on the habitats of plants, animals and people, can be harmful to health and reduce human well-being.

Working on the future of a sustainable energy system means developing solutions that enable the provision and use of energy with minimal environmental consequences. In addition to an optimised CO_2 balance, this also requires thinking and acting in terms of cycles. Technologies for the provision of energy should only be used if the resources utilised for this purpose can – to the greatest possible extent – be returned to a state that poses no further risk to the environment and this can be done at a reasonable cost.

This objective is a distant reality as illustrated by the following examples: e-mobility is still seen as a beacon of hope with respect to the contribution it can make to reducing global warming. However, there is as yet no economically viable solution for the complete recycling of lithium-ion batteries, which form the heart of this technology. The situation is similar for wind energy: real recycling is impossible for the rotor blades and gondolas (which weigh several tonnes) of wind turbines which comprise a combination of glass or carbon fibres with wood. Although not ideal, the situation is better for photovoltaic modules. During disposal, they are first dismantled into their individual components and cleaned. The silicon-based components are shredded and used for new electronic base plates (wafers). Here, a recycling rate of 90% is achieved. However, this process is energy-intensive and there are etching solutions that entail new environmental risks. A great deal remains to be done until the energy system takes the form of a real circular economy. Fundamental dilemmas include the land and spatial demands of energy infrastructure as well as its impact on biodiversity – while these aspects can be optimised, they cannot be eradicated.

Technology and innovation – overcoming the hurdles from knowledge to application

The transformation of the energy system requires technologies that reduce the consumption of fossil energy and serve to protect scarce natural resources. Current scientific and entrepreneurial developments have already facilitated spectacular cost reductions for renewable energy. The progress made in two extremely dynamic scientific areas – namely material sciences and information and communication technologies (ICT) – have been and continue to be especially relevant here. Material sciences, and especially the manipulation of materials at an atomic level, is at the heart of the developments in the areas of «wind energy» (ever larger rotor blades), «e-mobility» (batteries with higher energy densities and service lives), «photovoltaics» (greater solar efficiency) and «(bio)fuels» (improved catalysts and sensors). Thanks to the rapid progress in the ICT industry in areas such as «data management and storage», «big data analysis» and «real-time connectivity», a large number of new products and services are currently being introduced to the market. These are reducing energy consumption in the industrial sector, facilitating the use of renewable energy via smart grids in homes and supporting more energy-efficient forms of mobility.

Radically new products and services can often be attributed to the initiatives of small start-up firms. «Incubators» and «co-location programmes» at science parks are known means of promoting a strong link between these start-up companies and the scientific community. One challenge faced by many of these companies is gaining access to financial resources. The provision of capital is therefore key in getting through the foundation phase and ensuring promising concepts reach market maturity. However, companies will only invest in the development of new technologies if they expect there to be considerable market demand and they can generate earnings over the short to medium term. It is not yet easy to generate substantial demand for environmentally friendly products. The recently observed marked decline in the costs for renewable energy shows, however, that state measures aimed at opening up the market serve to motivate companies to increase production and reduce prices.

Weakened position in Europe

The Swiss electricity grid is closely linked to those of its neighbouring countries. This makes possible very high capacities for the import, export and the transit of electricity. Traditionally, Switzerland has enjoyed a relatively strong position within the organisations that have defined the standards of the European grid and further developed it. Due to the advancing integration of the European energy markets and the country's uncertain relationships with the EU, the influence of Switzerland has declined in recent decades, however. As a consequence of the liberalisation and harmonisation of the EU energy markets, many organisations are now subject to European jurisdiction. Switzerland is therefore becoming increasingly marginalised.

Negotiations for an electricity agreement with the EU have been under way since 2007. The EU has made it clear that without an institutional framework agreement it will not be possible to conclude the negotiations on the electricity agreement or other agreements on market access. Irrespective of an electricity agreement and the harmonisation of legal provisions, the European markets have a direct impact on pricing in the networked electricity market in Switzerland. The lack of an institutionalised link therefore hampers Switzerland's ability to guarantee grid stability and its market access; it prevents Switzerland from having a say on European developments in the non-technical committees.

Political legitimacy and the need for coordination

By approving the new Energy Act as part of Energy Strategy 2050, Switzerland's voters have provided the country's energy policy with legitimacy for the transformation of the energy system. The task of politicians is to realise these goals, stipulated in democratically legitimised processes, and to deploy the tools necessary to this end. The energy system also has characteristics that make state intervention essential – in addition to the failure of the energy market, these include the high costs for the energy network and the monopoly enjoyed by the energy suppliers. The external effects of energy production may also require government action, for example in cases where wind turbines have a negative impact on the landscape or financing needs to be secured for the follow-up costs of nuclear energy plants. State requirements can have an impact on all dimensions of the classic sustainability triangle, comprising the provision of supply security, the avoidance of a negative impact on the environment and the guaranteeing of affordable energy prices.

Federalism is a key element in Swiss energy policy. Table 1 provides an overview of the key areas of intervention of the different state levels. It shows the importance of vertical (e.g. support of renewable energy by the federal government and cantons) and horizontal coordination (e.g. transfer of tried-and-tested practices between municipalities). The international level and, in particular, the European level (see section 3.8) supplement the three levels of Swiss federalism.

The instruments of direct democracy allow citizens, interest groups and political parties to participate actively in energy-policy decisions. Ensuring political acceptance of energy-policy measures means a constant challenge for the authorities (see section 3.7), as well as the parties, to bundle diverging and often contradictory demands.

	Important areas of Energy Strategy 2050	Examples of coordination tasks
Federal government	– Energy standards for appliances and vehicles – CO_2 tax – Subsidies and discounts for green power – Regulation of the electricity market and electricity grids – Nuclear security including radioactive waste	Programme management by *SwissEnergy*, the platform that also supports the measures of the cantons, municipalities and private sector
Cantons	– Building renovations – Utilisation of waste heat – Promotion of renewable energy including hydropower	Harmonisation of cantonal standards in accordance with the model provisions of the cantons in the energy sector (MuKEn)
Municipalities	– Energy cities including mobility and sustainable districts	Inter-municipal cooperation at a regional level

Table 1
Action areas of public authorities

The transformation of the energy system – a task for society!

Whether as a consumer, economic player or voter, every person influences the energy system with their behaviour. With energy-saving behaviour in our everyday lives and conscious purchases and investments which are consistent with this, we all make an individual contribution to energy consumption. However, we are not fully independent in making our decisions. In accordance with our specific role and life situation – for example as young people, as a family or as retired individuals – our needs differ and are geared towards the relevant group's behaviour. As consumers, we can select products or appliances produced in an energy-efficient manner with low energy consumption if we possess the information required to do so. In selecting an energy source, our room for manoeuvre is often limited. Due to the limited free market, households are for the time being unable to choose from whom they wish to purchase electricity. The situation is similar for heating: with respect to their heating system or thermal insulation, tenants are dependent on the decisions of the real estate owners. Municipalities may also make it obligatory to connect to a gas or district heating grid. However, the role of individuals as voters comes into play through their decision-making. With their voting behaviour, they legitimise state interventions and guide them in the desired direction.

Overall, the mobilisation of society will prove a key instrument for the transformation of the energy system whether this is through achieving the consent of individuals to change their energy consumption patterns, increasing interest in energy-saving products and services, supporting local energy projects or creating acceptance for public investments, energy infrastructure or new regulations.

2.4 Development dynamics

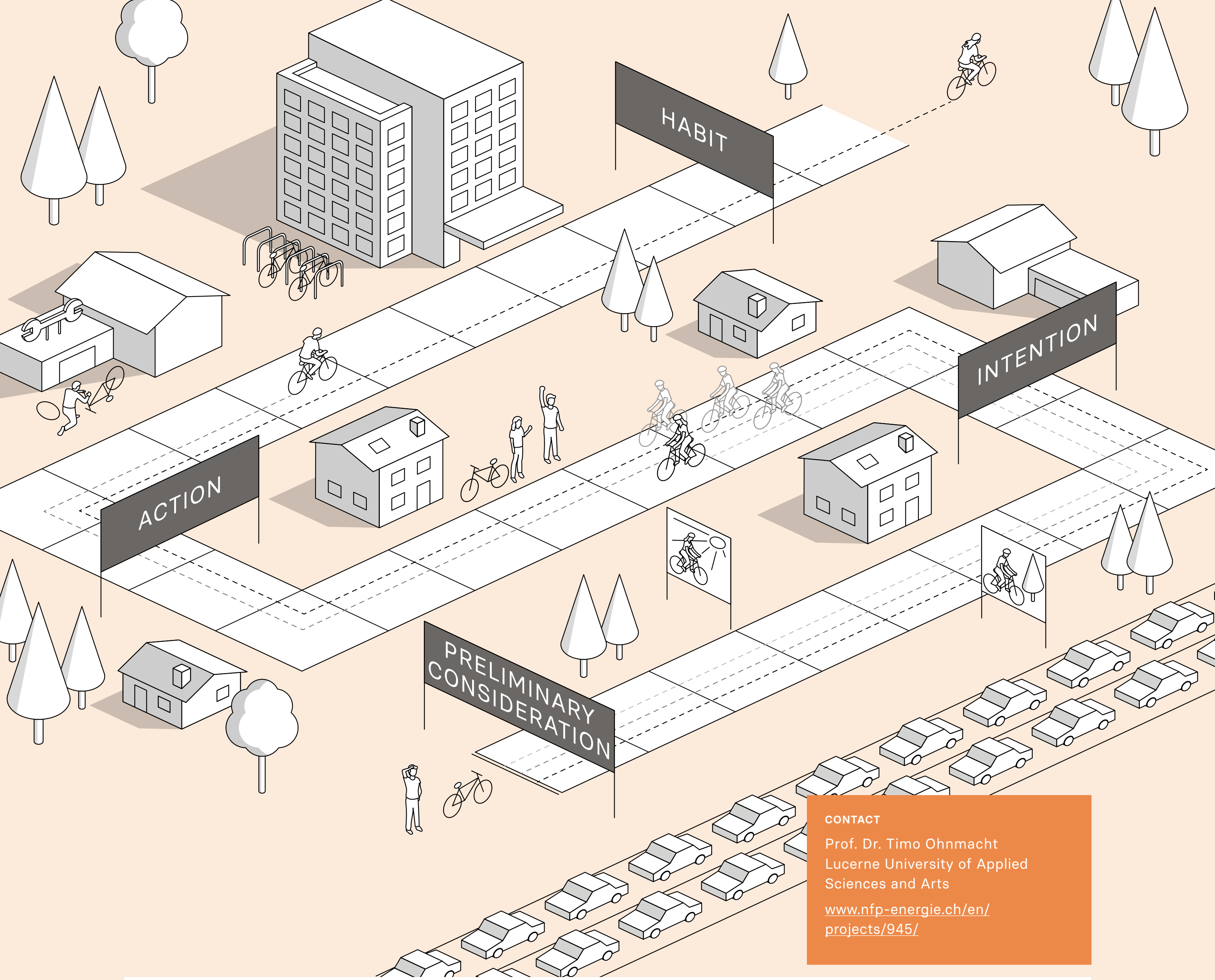
Varied Swiss energy history

With Energy Strategy 2050, Switzerland formulated objectives, negotiated as part of a complex political process, in a way that would achieve consensus. The country is thus writing a new chapter in its energy history – not for the first time, but rather against the backdrop of a rich energy history (see page 30–31) – where a certain degree of agreement has been repeatedly achieved on what the energy regime of the immediate future will look like. Such phases have encompassed stable regulations on use, tariffs and equipment standardisation. Each has been characterised by the use of new energy sources: the traditional regime of firewood and direct hydropower use was replaced in Switzerland in around 1860 by a regime shaped by the rapidly increasing consumption of coal and coke. During the late 19th century, the energy regime was expanded further with electricity generated from hydropower and coal. This was used for lighting and chemical processes before later also being utilised for drive systems and finally for heating applications. In the 20th century, oil was added to this energy mix, especially in the areas of shipping, mass motorisation, aviation and building heating systems. During the oil regime, plans for a nuclear-energy-based energy regime were already developed, although their implementation fell far short of original expectations. In contrast, over the past two decades the Swiss energy regime has been transformed by a whole host of new forms of energy sources and technologies: photovoltaic plants and wind turbines have supplemented electricity generation; in building heating systems, geothermal energy, natural gas and insulation techniques have started to play a major role; biofuels and all manner of electric vehicles have emerged in the motorised private transport sector. With the exception of natural gas, these new usage forms are discussed under the label of renewable energy (Kupper & Pulla 2016).

Energy markets – an object of political negotiation

It is not only today that energy markets are the subject of political debate. Whether in the past, the present or the future: all energy usage forms require regulatory protection mechanisms that enable them to develop. They are reliant on cross-subsidisation and are protected to different degrees by communal, cantonal and federal regulations. A politically balanced energy regime makes it possible to structure the future of the energy system in a manner capable of gaining consensus.

Bottlenecks in the supply of energy are an exception today. During the 20th century, the price of oil declined continuously thanks to production volumes. The phenomenon of prices falling over the long term – disregarding temporary war-induced highs – also applies to coal and this is also conceivable for renewable energy sources. Energy markets can only function well if suppliers can count on rising demand and falling production costs and if there are no bottlenecks in terms of consumption. Those who sell energy must also be able to do so in the foreseeable future and will thus want to expand their capacity on an ongoing basis and make the provision of energy more efficient.



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PROJECT #population #energy efficiency #sustainability

«Sustainable lifestyles and energy consumption»

How successfully the transformation of the energy system can be promoted also depends on the extent to which individuals can be persuaded to adopt energy-saving lifestyles. Whether someone behaves accordingly is essentially determined by socio-psychological factors. Based on the so-called phase model, the research team conducted a broad-based survey. The phase model assumes that people go through four phases before a new behaviour becomes a habit – from pre-consideration to intention and action to habit. The research team was able to show that different target groups can be won over with individually targeted information and measures for an energy-saving lifestyle. **However, the information and measures must correspond exactly to the phase in which someone is making a decision.** If people have never thought about energy-saving behaviour before, they can, for example, be persuaded to consider a change in behaviour by appealing to their emotions. On the other hand, those who have already decided to live more energy-efficiently require specific knowledge to implement this intention. The research team has developed guidelines for each of the six areas of life investigated. These illustrate in concrete terms how appropriate campaigns can be designed.

Anticipation – a necessity

An anticipation of future demand is not only required from an economic perspective, but also from a technical standpoint. An electricity supply grid with a capacity that is unable to fully cover demand immediately collapses – with devastating consequences for all consumers. The supply capacity must therefore always be greater than current levels of demand. In order to balance the precarious relationship between supply and demand, electricity companies have, since the late 19th century, concluded contracts where the capacity generated by their hydropower plants, which in the first instance service electricity-intensive applications and electricity exports, is gradually used for the general supply. This process was made easier by favourable financing conditions for communal, state and semi-private companies as well as through specialised banks in the equipment supply industry for private-sector power plants (Gugerli 1996).

The power plant operators controlled electricity consumption and thus the grid load using tariff incentives (off-peak electricity) and targeted appliance control (boilers, washing machines). In terms of provision, they operated a system of integrated load management by combining various power plant types. From the 1990s onwards, by promoting the sales of energy-efficient devices, especially those that were energy-intensive such electric cookers and storage heating units, the electricity companies were able to steer demand and thus pre-empt demand growth.

Social values shape the need for regulation

In economically liberal contexts, modern energy regimes are also characterised by a considerable need for regulation. A viable, but also flexible consensus must be developed and enforced on questions of safety, tariff structure, justifiable profits and subsidies, the formation of monopolies, the organisation of cartels, technical standards for infrastructure and apparatus up to and including acceptable forms of use and environmental damage. The more conditions an energy regime requires, the greater its need for regulation. And the more technical the work involved, the more condition-laden is the regulatory environment. The structuring of the regulations that characterise an energy regime is closely linked to the change in patterns of perception and interpretation. This is especially clear in the case of nuclear energy. At the end of the Second World War this was a problem of physics with a militarily deployable solution. The «civilisation of the bomb» had to reduce the high expectations placed on «nuclear energy» and at the same time allay the associated fears in a way that would see nuclear power plants become the most important application of this technology.

In Switzerland, nuclear power plants opened up a new scientific-policy field for the federal government. In one fell swoop, it opened the way for the formation of environmental policy, energy policy, regional policy and economic policy objectives as well as potentially even military goals. Around 1960, it appeared that the federal government and nuclear energy could enter into a perfect partnership: in terms of peace policy, such a programme was in line with the motto «swords to ploughshares» and also stimulated energy-policy self-sufficiency dreams while reducing the energy sector's dependency on coal and oil. Nuclear energy was thus a flagship of the federal government's technology policy (Gugerli et al. 2000; Gugerli 2004).

Overall, there was a very positive assessment of nuclear energy. However, its implementation would not only entail the splitting of uranium atoms, but also serve to split society. The failure of the federal experimental reactor in Lucens in the canton of Vaud, which was only in operation for one day, did not bother either the industrial sector or the political system (Wildi 2003). However, the conflicts surrounding the planned Kaiseraugst nuclear power plant, which lasted almost two decades, highlighted a whole host of problems relating to Switzerland's nuclear energy future. Nuclear energy, the federal government's technology-policy flagship, was associated with fears of a nuclear state, unscrupulous profit maximisation, enormous security problems, the threat of environmental damage and technocratic blindness and was reinterpreted as a symbol of a dystopia during the 1970s and 1980s (Kupper 2003). Accidents in Three Mile Island (1979) and Chernobyl (1986) put into perspective the reassurance that had been provided by safety-related regulations and the Probability Risk Assessment (Carlisle 1997). The residual risk remained. And while it was distributed to components, stakeholders and affected individuals, it was not eliminated (Beck 1986).

Many issues led to the approval of the «moratorium initiative» in Switzerland (1990). These included the downwards revision of energy demand forecasts, the rising production costs for nuclear-power-produced electricity , the evidence from quite normal disasters as well as the widespread diffusion of environmental awareness, including the problem of waste from nuclear power plants. The «moratorium» would subsequently form the basis of a brittle consensus that people started to get used to. With the increasing awareness of the CO_2 issue due to pressure concerning climate change, nuclear energy transformed into an attractive alternative to fossil fuels for a second time at the turn of the millennium. However, the Fukushima disaster (2011) once again changed the collective assessment of nuclear power to such an extent that the transformation of the energy system and the phasing out of nuclear energy gained a consensus. At the same time, the problem of climate change became more acute. With the approval of the Paris Agreement, Switzerland in 2017 committed to reducing its greenhouse gas emissions by 50% by 2030 relative to 1990 and announced an objective to achieve an overall reduction of 70% to 85%. This climate-policy decision also means the phasing out of fossil-fuel energy and should be implemented, among other measures, via the total revision of the CO_2 Act.

The long road to an energy-policy turnaround

The history of energy use makes clear: the transition from one energy regime to the next has in each case lasted longer than the talk would suggest of the «triumphal march» of electricity, the «1950s syndrome», the «1970s diagnosis» (Kupper 2003a) and the «turnaround» to renewable energy sources. Each energy regime has incorporated a very large degree of the past and the transitions have triggered intensive debate. Even major substitution processes have never brought about a situation in which an energy source has completely disappeared from the scene. On the other hand, new energy sources have always been linked to conflict-laden displacement processes, excessive expectations and fears, changes in relative prices, new state regulations, equipment innovations and changed levels of demand. Switzerland's Energy Strategy 2050 is a project that has been cushioned from an economic, environmental, energy, industrial and science policy point of view and, in the acid test of the 2017 referendum, it has proved capable of gaining consensus. It will form a point of reference for several years to come that action based on understanding is possible. However, this latest energy turnaround will also take a great deal of time and will only prove successful if it is able to offer new benefits on a continual basis.

People and energy – an inseparable link

For more than two million years, people have been attempting to supplement the energy of their own muscles with additional sources of energy and, through a variety of technologies, to make these usable. The first energy source to present itself was fire, which has always been available due to lightning strikes, coal-seam fires and volcanic eruptions. The earliest sources of fire unequivocally created by humans and dating back more than 1.5 million years were found in the Wonderwerk Cave in South Africa. In Europe, the first evidence of fireplaces comes from England, Southern France and Hungary; these are around 400,000 years old. The next two milestones are windmills in Babylon dating back to around 1700 BC and the water wheels developed by Greek engineers in the third and fourth centuries BC for agricultural irrigation. The first grain mills were described by the architect Vitruv in the first century BC. As far back as ancient times, the direct use of geothermal heat was widespread. This was primarily for bathing purposes but was also utilised for heating buildings.

In modern times, technological advancements have gathered speed. At the end of the 17th century, Denise Papin developed the first steam engine, which was later improved by James Watt. Wood was used as the primary energy source, although coal, which had been known since pre-Christian

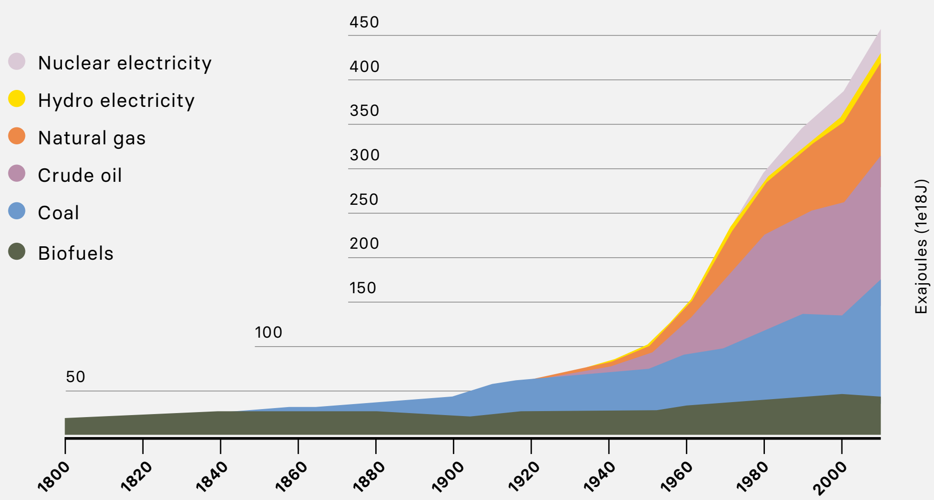

Figure 2

History of global energy consumption (Bice, undated).

times, was also increasingly utilised. In the 18th century, magnetism and electricity were systematically researched as energy sources. In 1859, Etienne Lenoir presented the first functioning gas combustion engine. This ultimately led on to the increased use of oil. Shortly before the Second World War, a group of researchers headed by Otto Hahn discovered the phenomenon of nuclear fission based on uranium.

The enormous rate of development since the end of the Second World War has primarily been based on the explosive increase in the consumption of fossil fuels (coal, gas and oil; see figure 2). The key drivers of this trend have been and remain population development and economic growth (see figure 3). The high and cheap availability of these energy sources has in turn also promoted this trend. It is obvious that things cannot continue to develop in this way – population growth needs to be slowed and energy consumption must be detached from economic growth. In other words, the link must be loosened. This poses societies and economies around the world with enormous challenges. There is an urgent need to increase energy efficiency and replace fossil fuels with new renewable energy sources.

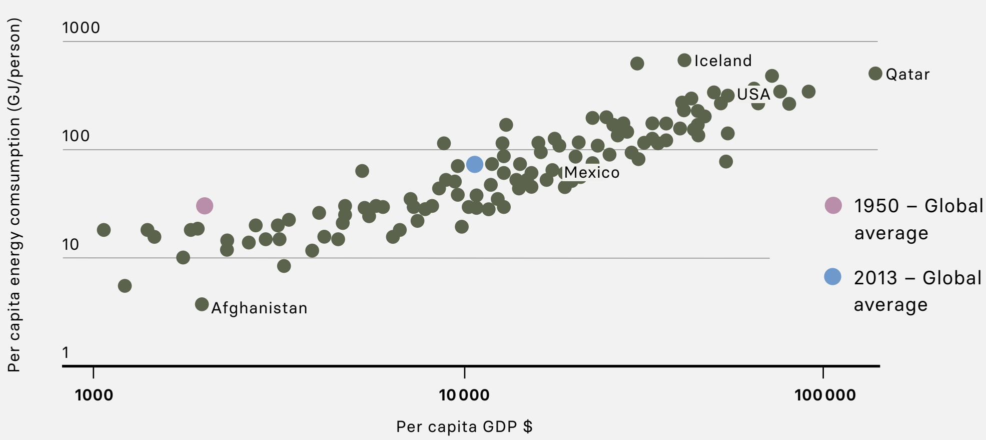

Figure 3

Relationship between GDP and energy consumption (Bice, undated).

The transformation of the Swiss energy system – as envisaged in Energy Strategy 2050 – will require activities in numerous areas – be these technical, economic, social or political. An outline of the key challenges that emerge from these, as well as selected results from the NRP «Energy» that contribute to overcoming them, is presented below.

3

Action areas of the transformation and approaches from the NRP «Energy»

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them, is presented below.

The research projects of the NRP «Energy» have developed numerous approaches that can contribute to the transformation of the energy system. Innovative technical developments to increase energy efficiency are just as much a part of this as are recommendations for shaping the political and legal framework or for generating acceptance of new technologies and behaviour.

3.1 Energy efficiency – a key to the energy turnaround

Increasing energy efficiency is one of the options for reducing energy consumption. The efficient use of energy not only means generating the same output while using less energy, but also avoiding unnecessary energy consumption. Another approach is sufficiency. This means bringing about a change in human behaviour, for example by means of mobility restrictions, lowering indoor temperatures during the heating period or sacrificing certain household appliances (see page 66).

Approaches for increasing efficiency

In 2017, 850,000 TJ of energy was consumed in Switzerland. Households and services together account for 44% of this total final energy consumption, primarily for running buildings. They are followed by transport with 36% (see figure 4).

Opportunities for increasing the energy efficiency of buildings with respect to heating and cooling can chiefly be found in connection with the building shell (roof, walls and windows). Insulation and the use of daylight and shading play a key role. During the past decade, energy labels have become established for lighting, household and office appliances and cars. These provide a reliable decision-making aid for consumers in selecting energy-efficient products.

Energy efficiency and effectiveness

Generally speaking, energy efficiency relates to a process within a technical system or device and corresponds to the relationship between the energy supplied and the useful energy. It is thus closely linked to the level of effectiveness, which reflects the relationship between the input power and the effective output. A lightbulb, for example, only converts around 5% of the consumed electricity into light. The lion's share – approximately 95% – is emitted as heat radiation to the surrounding area. While the lightbulb achieves an effectiveness rate of 5%, the corresponding figure for an LED lighting source is around 30% to 40%. For lights, however, it is the light yield (lumen/watt) and thus their efficiency that is the more suitable comparative figure. In the case of a lightbulb, this stands at around 10 to 20 lm/W. In contrast, a modern LED light source has a light yield of approximately 80 to 180 lm/W and is thus around eight to ten times more efficient.

In the case of industrial processes, energy is most commonly required in the form of mechanical energy or heating/cooling. Energy efficiency can be increased here through the application of energy-saving processes – for example by using continuous production techniques rather than batch production or by recovering waste process heat. Both approaches offer great potential but often require the conversion of tried-and-tested production processes and considerable investment.

Potential for increasing energy efficiency in the transport sector exists at a behavioural level as well as in organisational and technical areas. The greatest potential is offered by mobility behaviour, primarily via a switch from private transportation to public transport, the purchasing of energy-saving vehicles, an increase in vehicle occupancy and the use of carsharing[3]. In the technical area, a reduction in the weight of vehicles, the use of energy-efficient drive systems and the recovery and storing of kinetic energy are particularly important. This technical potential could be realised by vehicle users in making their purchase decisions provided that vehicle manufacturers make this potential available in the foreseeable future.

Slow renovation rate risks missing the targets in the building sector

In light of the significance of final energy consumption and the actual courses of action available, measures aimed at increasing energy efficiency need to be implemented in the short and medium term, especially in the building sector. In line with Energy Strategy 2050, according to which the final energy consumption of buildings is to be halved between 2010 and 2050, buildings and settlements

3 Synthesis on the main topic of «Mobility Behaviour» of the NRP «Energy». SNSF

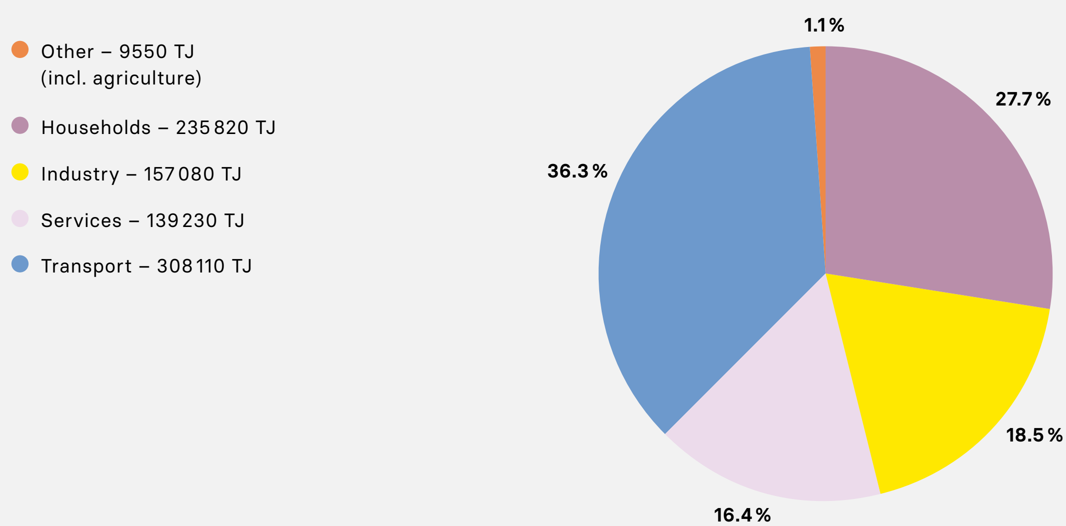
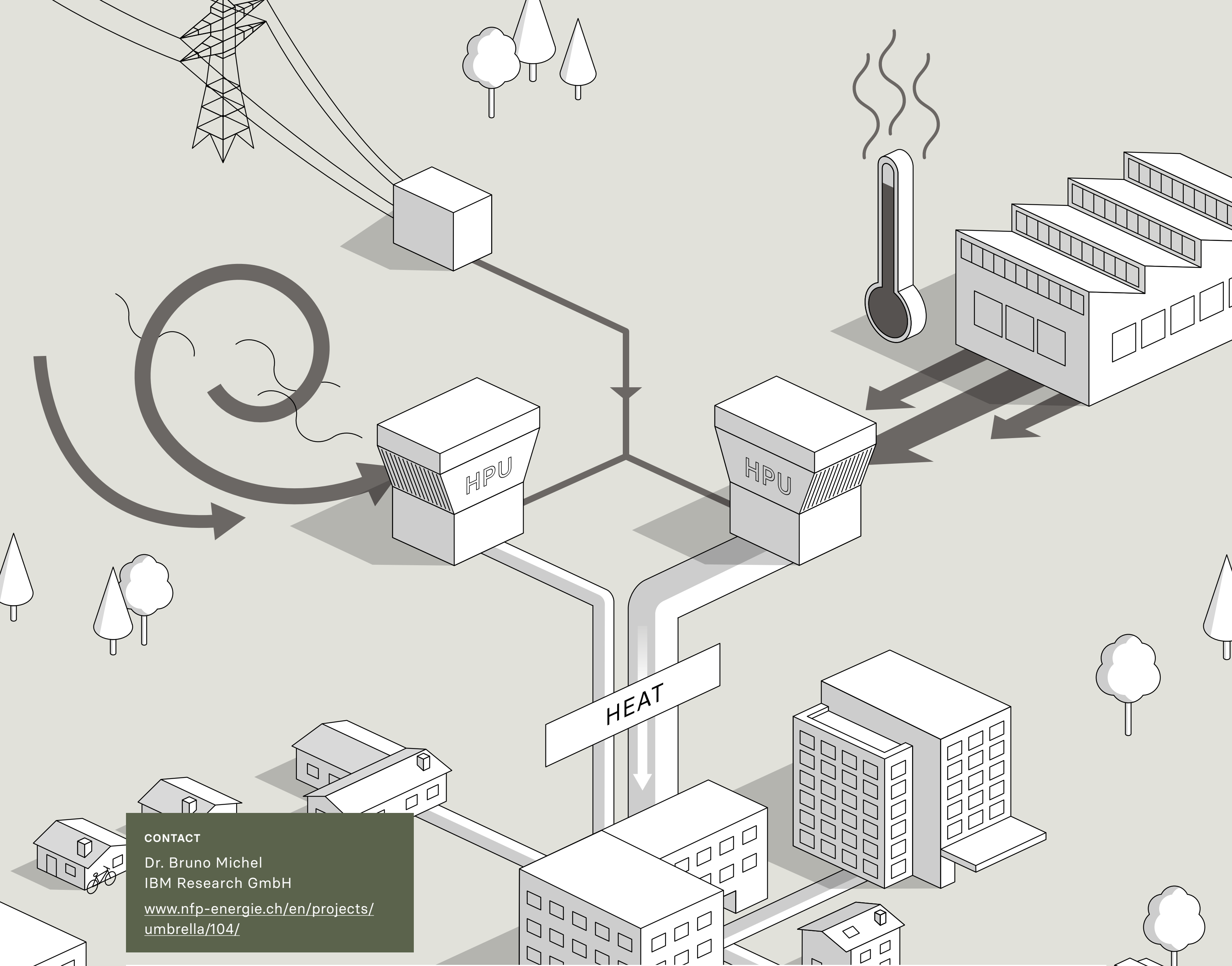


Figure 4

Swiss energy consumption in 2017 (SFOE 2018)



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PROJECT #cold / heat #heat pump #building

«Heat utilisation with solid sorption technology»

Instead of a liquid heat exchange, thermally driven adsorption heat pumps use a solid, very porous heat exchanger with water or methanol as a refrigerant. (Waste) heat is used as the drive energy. Current adsorption heat pumps are too expensive to purchase and are therefore not competitive with conventional heat pumps. The research team has succeeded in massively improving the technology, making these systems cheaper and more efficient. With these new adsorption heat pumps, the waste heat from industrial plants or photovoltaic systems can in future be used to heat office and residential buildings in a cost-effective and emission-free manner or to cool computer centres with their own waste heat. The research team analysed possible applications and market conditions for adsorption heat pumps in Switzerland and developed system and material technologies, including processes for the production of high-performance adsorption layers in heat exchangers. **The project has also highlighted the technical, environmental and economic potential of adsorption heat pumps.** This technology could therefore increase the capacity and energy efficiency of heating grids. Operating costs and emissions could be reduced for building heating and cooling systems.

therefore form a focus area of the NRP «Energy».[4] Due to climate change, the energy expenditure for the ventilation and air conditioning of buildings is set to increase yet further. The decline in energy expenditure for heating is likely to be equally as marked. With respect to energy efficiency and the reduction of CO_2 emissions, new buildings no longer pose a problem. With reasonable additional costs, new buildings can substantially reduce their energy requirements. Furthermore, they can produce a substantial share of their remaining electricity and heating needs themselves and without CO_2 emissions. What is «state of the art» for new buildings is only slowly being realised for old buildings. As the project «Determinants of energy-efficiency investments» states, the general renovation rate for residential and office buildings is only around 1.5% per year (Ott et al. 2013).[5] In the building sector, the timely achievement of the objectives stated under Energy Strategy 2050 is therefore at great risk. For old buildings that were constructed prior to the turn of the millennium, there is thus a considerable need for action.

Measures for increasing efficiency in the building sector

If the energy efficiency of the building stock is to be increased, measures will be required, in particular, in two areas: for energy-optimised building shells and the intelligent management of energy supply and demand.

With the systematic insulation of the building shell (roof, facade and ceiling above a non-heated basement floor) and windows with a low heat transmission coefficient, heating and cooling needs can be considerably reduced, especially in the case of new buildings. So that such measures are also actually implemented, binding targets are required. Thanks to correspondingly challenging targets, the heating requirements of new buildings have been reduced to one-sixth over the past 40 years (see figure 5). Glazing, especially for office buildings, offers considerable potential for improving efficiency. Current developments at the Swiss Competence Centre for Energy Research – Future Energy Efficient Buildings & Districts (SCCER FEEB & D)[6] are making possible dynamic glazing that automatically controls the amount of sunlight coming into a building based on the position of the sun and at the same time reduces the incoming heat radiation and thus also the need for cooling. Other innovative glazing systems aim to ventilate the spaces between the layers of glass in order to dissipate the radiation heat. Provided production costs can be reduced substantially, these technologies will offer considerable potential for boosting efficiency. The artificial lighting of workplaces should in future be based on the light intensity actually required. The lighting control systems needed for this purpose are operated automatically by means of sensors that are linked to a presence monitoring solution and the window shading system.

Using a method developed as part of the project «Demand and storage in electricity networks», the energy consumption of buildings and the devices linked to them can be managed in such a way that energy can be stored over a broad time spectrum, i.e. short to long term.[7] This enables ongoing energy costs to be reduced by around a quarter – without any loss of comfort for the building users – and for the need for decentralised batteries to be reduced significantly.

In the project «Regulations for the building stock», methods were developed that maximise energy efficiency, the reduction of CO_2 and the generation of renewable energy overall either for individual buildings or across entire settlements. This requires the comprehensive consideration of all structural-physical and technical aspects that are affected by energy provisions.[8] The cantons are required to implement these aspects in connection with the current model provisions of the cantons in the energy sector (MuKEn).

4 Synthesis on the main topic of «Buildings and Settlements» of the NRP «Energy». SNSF

5 [Determinants of energy-efficiency Investments]

6 www.sccer-feebd.ch

7 [Demand and storage in electricity networks]

8 [Regulations for the building stock]

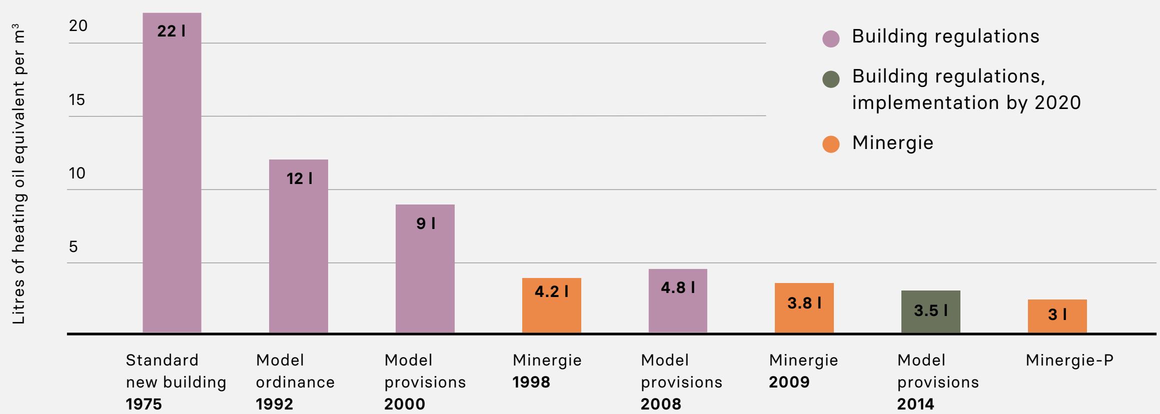


Figure 5

Development of regulations and standards for the heating requirements of new buildings (heating and hot water) over the past 40 years (Cieslik & Knüsel 2018)

Untapped efficiency potential in businesses

With Energy Strategy 2050, businesses are confronted with major challenges (see section 3.2). Energy-intensive businesses[9] in Switzerland have reduced their energy consumption since 1990 by a third[10]– primarily to improve their market position. Nevertheless, there is still substantial savings potential. Depending on the sector in question, this potential amounts to up to 15% for electricity (cement) and up to 60% for fuel (food), as determined by an SCCER EIP study (Wallerand et al 2018). Savings can primarily be realised in the «food», «pulp and paper» and «chemicals» industries through systematic heat recovery and the use of heat pumps and ORC processes (Organic Rankine Cycles).

Potential for increasing energy efficiency cannot only be found at companies in terms of their operating processes, but rather also in connection with their business premises.

Energy management: key to success

In the project «Determinants of energy-efficiency investments», around 300 Swiss businesses were surveyed on the issues of «energy management» and «energy-saving investments».[11] It was revealed that large companies, and especially those with a high level of energy intensity and a global focus, generally operate a professional energy management system, have employed a qualified energy manager and have formulated energy-saving objectives. They also possess the corresponding budgets to this end. Stringent energy management

9 Companies for which energy costs account for a share of more than 15% of gross added value; primarily from the «cement», «iron and steel production», «chemicals», «food» and «pulp and paper» industries.

10 www.eneff-industrie.info

11 [Determinants of energy-efficiency Investments] of this kind directly leads to substantial energy savings. For small and medium-sized enterprises (SMEs), energy consumption is also an important issue. In most cases, however, it is only addressed in connection with other business investments. At most companies, there is a need for action with respect to systematic monitoring and performance checks for implemented energy-saving measures.

When it comes to stringent energy management and the implementation of energy-saving measures, great importance is attached to the provision of support by top management (Iten et. al 2017). The issue of energy at companies must therefore be established at the highest management level and be handled with the corresponding level of management attention. In other countries, regulatory measures are also in force. In the Netherlands, for example, all companies are required to develop an energy-saving plan.

Efficiency potential for energy suppliers and urban freight logistics

Potential for improving efficiency not only exists for energy consumers, but rather also, for example, in the areas of energy provision and transmission and of urban freight logistics.

At hydropower plants, for example, sediments lead to the abrasion of hydraulic systems. At medium- and high-pressure power plants in Switzerland, inadequate desanding systems lead to annual production losses of an estimated 160 GWh. The project «Sediments in high-head hydropower plants» has revealed that the sediment load can be limited by making improvements to these facilities.[12]

According to estimates of the project «Smart urban freight logistics», intelligent urban freight logistics systems, which incorporate all transportation, handling and storage processes in connection with goods, packages and courier services, could make a contribution of around 7% towards achieving Switzerland's energy-policy objectives and of 9% to the country's climate-policy goals by 2050.[13] To this end, coordinated measures would be required on the part of logistics companies. In particular, these would also include the use of hydrogen-powered vehicles as well as action from the cities and cantons in the areas of «spatial planning» and «transport infrastructure» with the aim of optimising the logistics infrastructure.

3.2 Renewable energy sources

Energy Strategy 2050 focuses greatly on the expansion of renewable energy in order to facilitate the phasing out of nuclear energy and fossil energy sources. By 2020, excluding hydropower, these resources should generate at least 4,400 GWh, with the figure rising to at least 11,400 GWh by 2035.[14/15]

Opportunities for optimising and expanding hydropower[16]

The generation of electricity through hydropower is cost-effective, efficient, climate-friendly and, in many respects environmentally friendly. Thanks to its topography and considerable average precipitation, Switzerland offers ideal conditions for the utilisation of hydropower. This today covers around 60% of Switzerland's energy consumption. Under Energy Strategy 2050, hydropower should make a contribution to replacing the electricity produced at nuclear power plants.

12 [Sediments in high-head hydropower plants]

13 [Smart urban freight logistics]

14 Swiss Federal Constitution (FC; SR 101): Art. 89(2) FC

15 Energy Act (EA; SR 730.0): Art. 2

16 Synthesis on the main topic of «Hydropower and Market» of the NRP «Energy». SNSF

However, the opportunities for expanding hydropower in Switzerland are limited. Focus is thus being placed on the optimised use of existing hydropower plants. Hydrometeorological predictions that go beyond the time scale of weather forecasts – for periods of more than two and up to four weeks – can make a contribution here. In particular, forecasts for the inflow and outflow of water can be combined with the expected price developments on the energy market. This combination permits the operation and economic viability of storage power plants to be further optimised. The incorporation of these hydrometeorological predictions in the operational planning of power plants facilitates a production increase of 4% to 6% per year.[17]

In Alpine areas, retreating glaciers are freeing new zones that would be suitable as possible sites for reservoirs and which could thus offer new usage opportunities for hydropower. The first new glacial reservoirs are already forming. In order to cover the expected electricity deficit of 1.1 TWh per year up to 2035, at least seven new hydropower plants in regions close to glaciers would be required.[18] Such reservoirs could – as a positive side effect – support winter electricity production with a storage capacity of around 1.3 TWh. However, most of the considered locations are situated in areas with a protected status.

There are further environmental challenges relating to hydropower. Since residual flow remediation measures are still outstanding, production losses are to be expected. In the project «Sustainable floodplain management and hydropower», it is also shown that the implementation of the residual flow provisions is not sufficient in order to preserve the biodiversity found beneath dam walls and water catchments (see page 43).[19]

17 [Hydrometeorological predictions]

18 [Periglacial zones and hydropower]

19 [Sustainable floodplain management and hydropower]

Technological and design progress in the area of solar energy

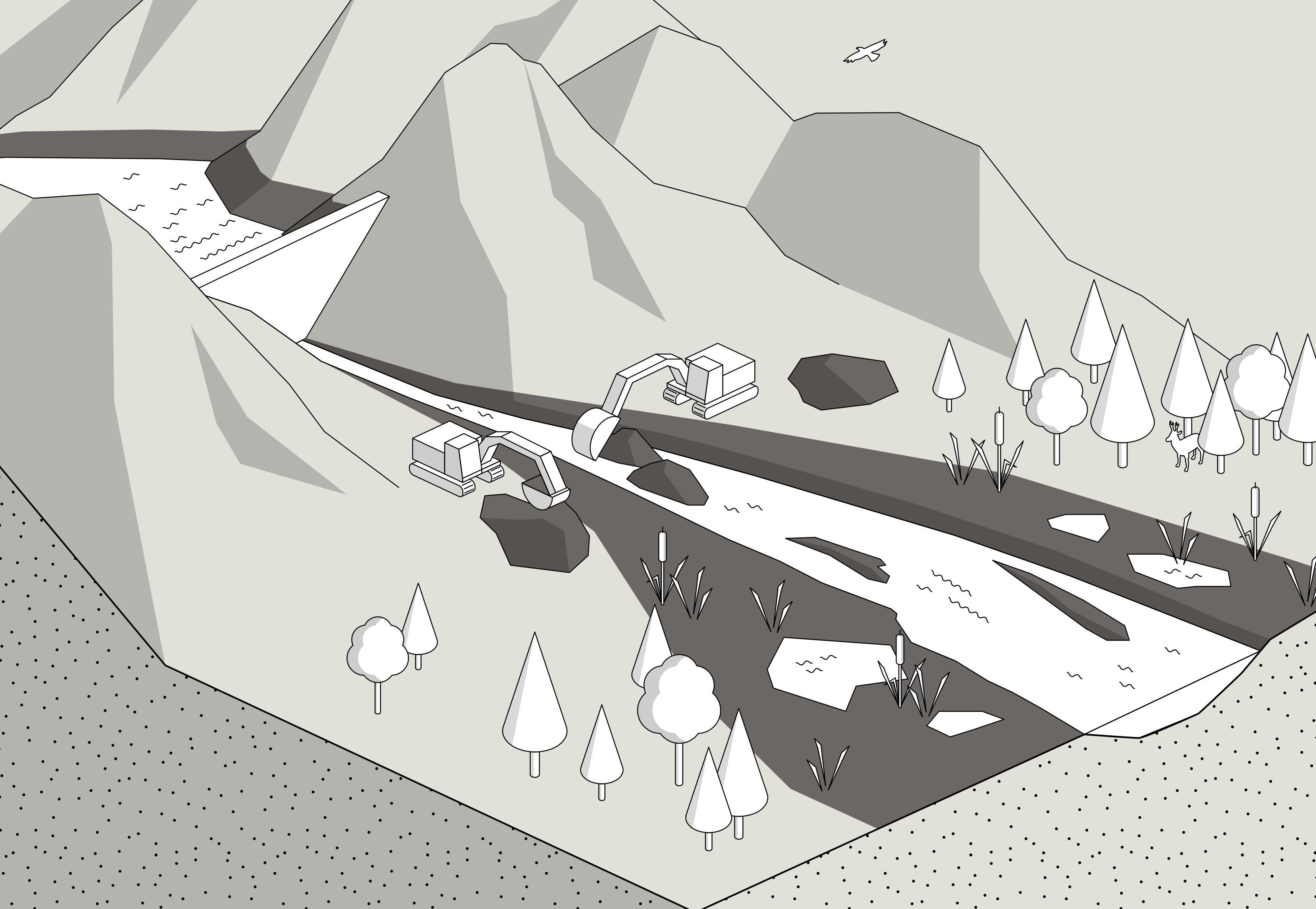
Solar radiation or simply solar energy can be converted directly into heat or electric energy. For use as thermal energy, solar energy is absorbed by solar panels. A storage medium is heated with this energy and provides this heat for the preparation of hot water or for heating systems via a heat exchanger.

Photovoltaic systems (PV) and solar thermal power stations are the two concepts that lend themselves to the conversion of solar energy into electric energy. Photovoltaic systems comprise solar cells that are built from semiconductor layers and which generate direct current when struck by photons. An inverter converts this into alternating current. In solar thermal power plants, the thermal energy is absorbed by panels. Using a heat exchanger, this energy is used to generate steam and power a conventional generator. As part of the joint project «Next generation photovoltaics», the NRP «Energy» made important contributions to the further development of solar cells, especially with respect to the use of new materials and thus to increasing the efficiency of the cells (see page 45 and page 64).[20]

In 2017, around 700 GWh of thermal energy was generated by solar panels in Switzerland (Eicher & Pauli 2018). Photovoltaic systems, however, are the main part of Energy Strategy 2050. At the end of 2017, their installed capacity stood at 1,906 MW, while their annual production amounted to 1,683 GWh (SFOE 2018a). The expansion of the installed capacity accelerated considerably between 2005 and 2013, but subsequently stagnated and even declined slightly.[21] It is anticipated, however, that the expansion will step up once more. In addition to systems on roofs, building-integrated PV also offers potential – i.e. solar cells as facade elements or roof tiles which to date have enjoyed a niche existence. In the city of Neuchâtel, the project «Accelerating PV applications» identified

20 [Next generation photovoltaics]

21 www.swissolar.ch/nc/en/



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projects/1021/

PROJECT #hydropower #landscape #ecology / environment

«Sustainable floodplain management and hydropower»

In river sections below dams and dam walls, water flows continuously in small quantities – as required by law. This water is referred to as the residual flow. However, there is no natural flooding. Algae therefore settle in the riverbed and ever greater areas of the channel are covered. The waters become impoverished and forest areas develop. The walls and dams also interrupt the transport of gravel and sand. In an experiment, the research team investigated the effects of an artificially generated flood on the biological communities in the lower reaches of the Saane river downstream of the Rossens dam FR. The flood flushed out the overgrown vegetation on the gravel banks and transported water to previously dried up side channels. The artificially generated flood therefore had a positive effect on the alluvial landscape. The addition of boulders with artificial deposits in the Saane played an important role here. **To achieve a long-term benefit for the ecology of the alluvial landscape, it is necessary to trigger floods with bedload replenishment regularly.**

good potential for the realisation of building-integrated PV systems for 45% of building permits. A lack of knowledge, low social pressure and high costs were found to be obstacles here (see page 22).[22] As the results of the project «Energyscapes» show, however, photovoltaic systems enjoy a high level of acceptance in settlement areas.[23]

Wind energy faces acceptance problems

Wind energy plants utilise the kinetic energy of the wind to produce electricity. Horizontal-axis wind turbines with three rotor blades are the predominant solution here. The produced power can be influenced by the angular position of the rotor blades. The turbines power a generator that converts the mechanical rotational energy into electric energy. In 2017, around 132 GWh of electric energy was produced via wind turbines with a capacity of 75 MW (SFOE 2018a).

However, the realisation of wind energy plants, and especially larger-scale wind parks, must take account of a large number of framework conditions, for example noise-protection or being in conflict with bird migration areas. The federal government's «wind energy concept» (ARE 2017) defines, among other things, the key national interests that need to be taken into consideration during the planning process. However, wind energy plants also have to tackle considerable acceptance problems in other regards. For example, the more wind turbines that are visible in a landscape, the lower the acceptance of these plants. In combination with photovoltaic systems the assessment is slightly better, while acceptance levels are slightly worse when combined with high-voltage power lines. Acceptance also depends on the characteristics of the landscape. For example, wind energy plants enjoy a greater level of acceptance in areas that have already been impacted, for example in Switzerland's settlement-rich Mittelland region or in areas with existing tourism infrastructure, than they do in other landscapes. Even in the lowland areas shaped by agricultural activities, there is only a moderate preference overall for a few wind systems – in combination with photovoltaic systems – on buildings. In comparison to other landscapes such as the Jura, Alpine foothills and mountain regions, however, they are rated relatively positively. The landscape zones in which renewable energy is preferred are, in many cases, not aligned with those identified by the federal government as areas with wind-power potential. The latter incorporate areas which have high wind energy yields, are consistent with the most important federal interests and which can support a sufficient concentration of turbines in the available space.

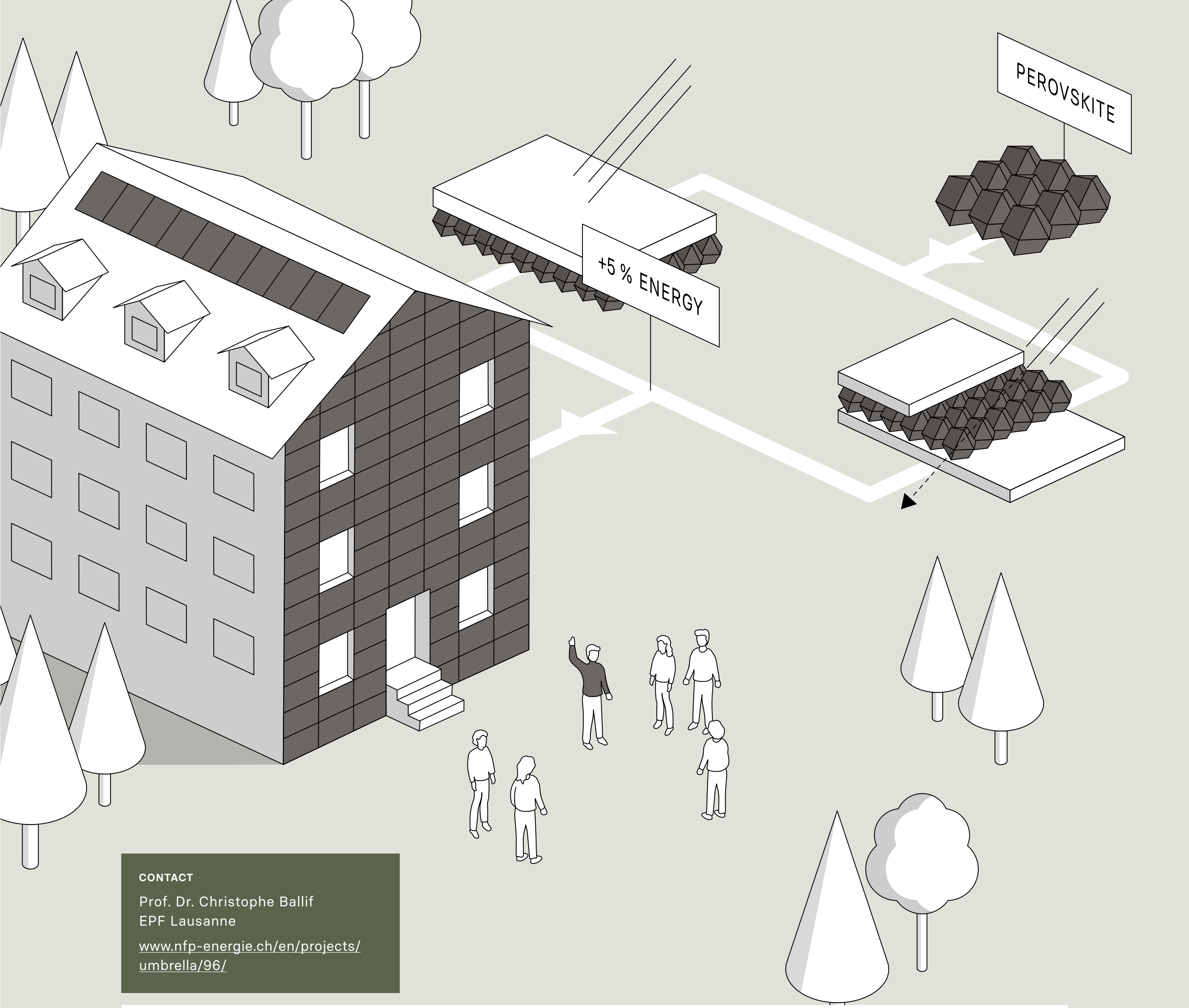
New perspectives for deep geothermal energy

Geothermal energy uses the heat from the Earth's crust for the heating of buildings via heat pumps or for the production of electricity using steam turbines and generators. Here, a liquid is heated underground. The heat extracted in this way is delivered to another liquid in a heat exchanger or a heat pump and can thus be used for the heating of buildings. Just a few metres beneath the Earth's surface, geothermal heat can be used for heating systems with earth collectors. Borehole heat exchangers for the provision of heating or cooling are used from a drilling depth of around 50 metres. Heat can likewise be used from other environmental media, including from the air, groundwater and lakes. The use of geothermal heat via heat pumps for heating purposes is very widespread in Switzerland. Around 15% of building heating systems are fed by geothermal heat pumps (SwissEnergy & SFOE 2018a).

At geothermal power plants, the generated steam powers a turbine. This requires the temperature in the heat cycle to reach at least 100 degrees Celsius, which in Switzerland usually only occurs from a depth of a couple of thousand metres (SwissEnergy & SFOE 2017). Due to the earthquake risk from deep drilling, no geothermal power plants have been commissioned in Switzerland to date. The lack of techniques for controlling the seismic consequences remains one of the main hurdles to overcome for geothermal electricity production in Switzerland. Appropriate risk management and

22 [Accelerating PV applications]

23 [Energyscapes]



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PROJECT #photovoltaics #building #acceptance

«Next generation photovoltaics»

There are alternatives to the currently known photovoltaic technologies based on crystalline silicon and copper indium gallium selenide (CIGS) that convert solar energy photons more efficiently. A higher electricity yield can be achieved, for example, with tandem cells in which differently structured cells are combined.
The research team developed fully functional systems for innovative tandem cells that combine crystalline silicon cells with perovskite cells (see p. 68). These can be provided with additional layers which, for example, facilitate optimum light management. Overall, efficiency levels of 27% to 30% can be achieved – in excess of five percentage points more than conventional cells. Although there are still numerous hurdles to overcome, these solar cells offer great industrial and energy potential. If ideally aligned roofs and facades in Switzerland are equipped with these cells, they could increase the current basic potential on buildings of 67 TWh of electricity by between 13 TWh and 14 TWh thanks to the improved efficiency.

data-based real-time strategies can reduce the technical risk of triggering seismic events. The damage caused by so-called microearthquakes, which can be triggered by the injection of water into deep rock layers, has been difficult to predict until now. Newly developed methods from the project «Risk management for geothermal power and hydropower» contribute to gauging potential damage from microearthquakes. This generates a more precise picture of the overall risk at geothermal power and hydropower locations, meaning that the risk-cost-benefit ratio can be assessed more soundly. Communication channels also help to better understand the wishes and fears of the public and thus to address the social component.[24]

Findings from the project «Deep-heat mining» conducted at the Grimsel Pass are also opening up new perspectives. Tectonic fracture zones in the central Alps and the area around the Rhone Valley could represent promising sources for high-temperature geothermal energy and thus for the generation of electricity or heat (see page 75).[25]

Progress in the generation and use of hydrogen

Hydrogen (H_2) is not directly available as an energy source. However, when produced by means of power-to-gas technology (see page 53) using electricity generated from renewable energy, hydrogen opens up opportunities for numerous applications, especially in fuel cells and thus also for the powering of electric vehicles. How sustainably drive systems of this kind can be structured is fundamentally dependent on the resources used during the production of the H_2. Provided the electric energy used actually originates from renewable resources, the greenhouse gas emissions in the cycle as a whole can be reduced considerably when production is conducted via electrolysis.[26] Material characterisation in three-dimensional models as well as mathematical models of the project «PEM fuel cells» enable the conversion process of H_2 in fuel cells to be better analysed and for this to be made more efficient. PEM fuel cells are characterised by a favourable ratio between thermal and electric efficiency as well as quicker conversion dynamics. The project «Technical evaluation of multi-energy hub systems» revealed that so-called PEM fuel cells are best suited for use in private combined heat and power systems.[27]

Until now, however, the production of hydrogen has been very costly. To bring about its widespread use, technologies will be required that make it possible for H_2 to be produced in a more efficient and cost-effective manner. The cutting-edge technology in this area, namely the generation of hydrogen from sunlight and water using semiconductor materials, is not yet suitable for large plants and production volumes. However, the use of new materials in the project «Photocatalytic water splitting» makes possible an increase in efficiency.[28]

Usage potential for wood and waste

Biogas generated from fermented biomass (organic material such as crop residues, manure and compost) can be used for the provision of heat and electricity. Wood is also classified as «biomass». The organic components of waste (compost, wood, etc.) can likewise serve as renewable energy sources (VSE 2018)

Wood is predominantly burnt. The heat generated can be used directly for the heating of buildings. By contrast, power plants that use biogas and waste incineration plants are operated as combined heat and electricity production plants. In 2017, the energy recovered from biomass (incl. wood) and waste provided around 10,400 GWh of thermal energy and 1,720 GWh of electric energy. This corresponds to around 65% of the heat generated from renewable energy and around half of the electric energy (excl. hydropower) (SFOE 2018a).

24 [Risk governance for geothermal and hydro energy]

25 [Deep-heat mining]

26 [Sustainability of methanation]

27 [Technical evaluation of multi-energy hub systems]

28 [Photoelectrochemical water splitting]

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PROJECT #recycling #industry #politics (federal government, canton, municipality)

«Waste management to support the energy turnaround»

A great deal of energy can be sourced both directly and indirectly from waste. For example, municipal waste with an energy content of around 30 PJ is incinerated in Switzerland every year. The direct contribution made by waste-incineration to Swiss electricity production amounts to 3% of the total. The contribution to the heating supply for households and industry, made via a waste incineration plant's (WIP's) district heating grid or steam network, can be well above 80% at a local level. Based on scenarios, the research team demonstrated the following: **the greatest potential offered by waste management lies in obtaining secondary raw materials during the recycling process, thus indirectly making possible the avoidance of the energy-intensive production of primary raw materials.** However, the level of energy saving depends significantly on the quality of the collected material. Furthermore, thermal utilisation generally proves to be more interesting from an economic perspective when full cost accounting is applied. The research team also sees opportunities to increase energy efficiency in WIPs. Some of these are not situated in close proximity to energy consumers who could make optimum use of the heat. Waste management can also be more energy-efficient if it is increasingly organised along the value chains and strengthens cooperation between the federally-organised stakeholders.

In Switzerland's forests, more wood grows than is currently used. Some of this could be used, for example, to heat residential buildings. With the combustion, pollutants that are detrimental to health escape into the air. If wood heating systems are to be installed more frequently in settlements, then suitable combustion types must be used and the plants must be operated in an optimal manner. Two projects of the NRP «Energy» have addressed these aspects. They conclude that clear preference should be given to automatically operated combustion systems. Under optimal operating conditions, they emit up to 2,400 times less pollutants than manually operated systems. As many pollutants are emitted during the start of the combustion process, in particular, good planning with respect to heating requirements helps the combustion systems to be run as continuously as possible and thus to keep pollutant emissions low.[29]

In 2012, Switzerland's waste contained energy totalling around 35,000 GWh. As explained above, this can be utilised directly via combustion and the provision of heat and electricity or via recycling. It can also serve indirectly to save energy at other points by replacing primary materials. With high quantities of waste, the energy recovered both directly and indirectly can be more than doubled by 2050.[30] Even if waste quantities decline by 40%, it would still be possible to recover 10% more energy. Recycling also plays a very important role provided this actually serves to replace primary materials (see page 47).

29 [Wood combustion for energy in buildings]

30 [Waste management to support the energy turnaround]

3.3 Distribution and linking of energy sources

The higher share of solar and wind energy in the energy system of the future will lead to more marked fluctuations in the energy supply. Furthermore, there will be more and more decentralised energy providers. In order to keep the energy system stable while ensuring the required level of flexibility, distribution strategies that guarantee exchanges in both spatial and temporal terms as well as between the difference energy sources (convergence) are required. In addition to the actual infrastructure (transmission and distribution lines, storage solutions), organisational measures in the form of new grid control and load management systems that balance the various loads as flexibly as possible will also be needed. Due to the increasingly complex nature of the energy system, enormous significance is attached to this task that cannot be mastered without comprehensive digitalisation.[31]

Planned electricity grid expansion – prerequisite for supply security

In order to meet the high requirements that will be placed on the electricity grid of the future, 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 project «Future energy infrastructure» revealed that the planned expansions of the Swiss transmission grid (see figure 6) are necessary in order to guarantee supply security – under different development scenarios. With this expansion, the grid will be able to handle the future energy flows. A more extensive expansion will not be required, however.[32]

31 Synthesis on the main topic of «Energy Networks» of the NRP «Energy». SNSF

32 [Future energy infrastructure]

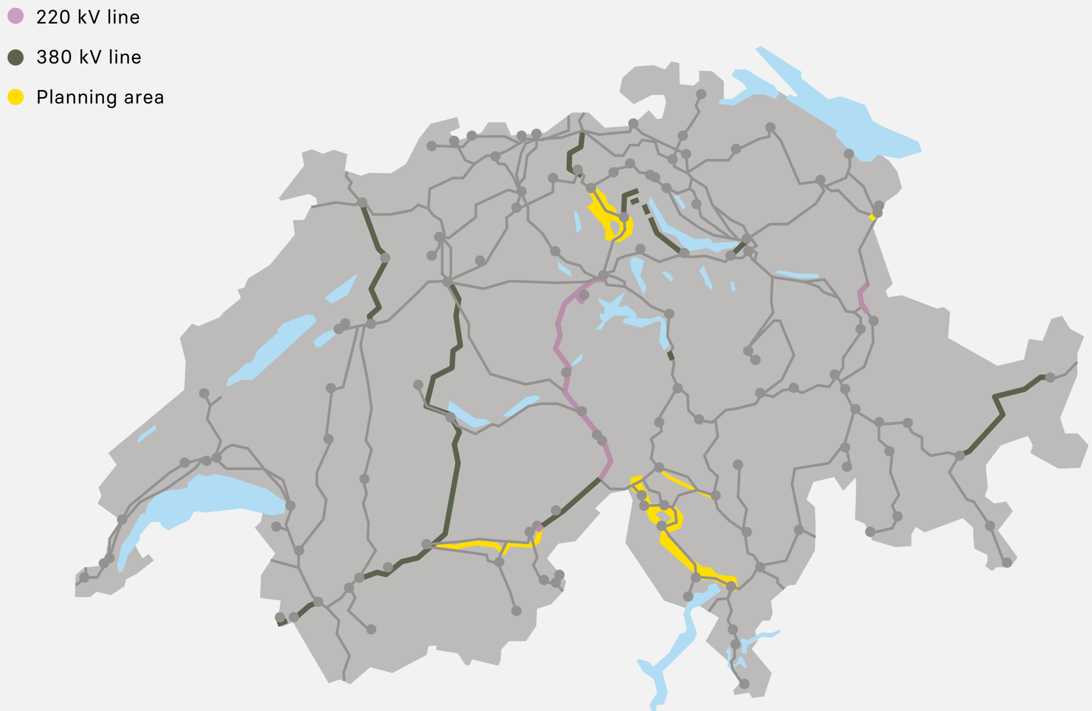


Figure 6

Planned expansion of the electricity grid (Swissgrid)

The project «Hybrid overhead power lines for Switzerland» also shows that a combination of alternating current (AC) and direct current (DC) lines in a joint line corridor – so-called hybrid overhead power lines – could contribute to increasing transmission capacity and strengthening grid security. An optimal configuration would make it possible for the emissions associated with the lines – the noise and the strength of the electromagnetic fields – to be reduced.[33]

Further development of storage technologies

Storage technologies have played a key role in Switzerland's electricity supply system for a long time. In particular, they have served to take on surplus base-load energy from nuclear power plants during the night before feeding it back into the system during the day at times of high electricity demand. However, the current interest in storage options also centres around the flexibility that is necessary to balance out short-term and seasonal fluctuations.

The variety of storage technologies is immense. Pumped-storage and hydropower plants with reservoirs are by far the most common electricity storage technology. They possess relatively large

33 [Hybrid overhead power lines for Switzerland] energy and output capacities. However, their potential for expansion is very limited. Battery storage systems are increasingly being used. In particular, these are being utilised by building owners with photovoltaic systems. But energy suppliers are also starting to install battery storage solutions, thus enabling them to provide control energy, for example (EKZ 2018). Promising potential is being opened up by metal-air batteries, which are able to store up to 30 times more energy than conventional accumulators in the same area (see page 59).[34] However, there is still a long way to go and a great deal of uncertainty to overcome before this technology is applied in practice.

The project «Electricity storage via adiabatic air compression» has demonstrated the practical feasibility of compressed air storage technology (see page 55). Here, air is compressed using a compressor and stored in a cavern. The compressed air is then used at a later time to generate electricity again.[35]

Other storage technologies include flywheel generators and condensers. These receive relatively little attention in Switzerland, however. Particular importance is being attached to the linking of different energy sources as a future storage strategy («Power-to-X» stores, see page 52). With the increasing networking of the energy system, the optimal combination of short- and long-term storage solutions is also gaining in importance. This depends greatly on the pursued objective (e.g. cost optimisation, minimisation of CO_2 emissions) as well as the configuration of the respective system, for example the share of renewable energy sources.[36]

Load management as a future task

Due to the increasing number of decentralised energy providers, the level of decentralisation in Switzerland's electricity supply will increase in the energy system of the future. Decentralised providers – so-called prosumers – are changing the voltage and load flow profile in the grid. Load management is tasked with controlling the system in light of its increasingly complex and networked structure and with adjusting electric power requirements in line with available power plant capacity, for example by means of differentiated tariffs (high and low tariff), restricted periods or connecting and disconnecting electricity consumers based on the situation at hand.

A very simplified form of load management is achieved with the high and low tariff regime. It provides the incentive to shift consumption from daytime hours to off-peak periods or weekends. Intelligent measurement systems, so-called «smart meters», permit greater temporal flexibility in term of control, for example through the quarter-hourly measurement of individual electric energy consumption. «Smart meters» can also accept signals. The Federal Council's proposal to replace 80% of traditional electricity meters with this new generation by 2027 provides the opportunity to integrate consumers in the balancing of energy provision and consumption to a greater extent. Various companies already offer products that should make use of this flexibility with customers.

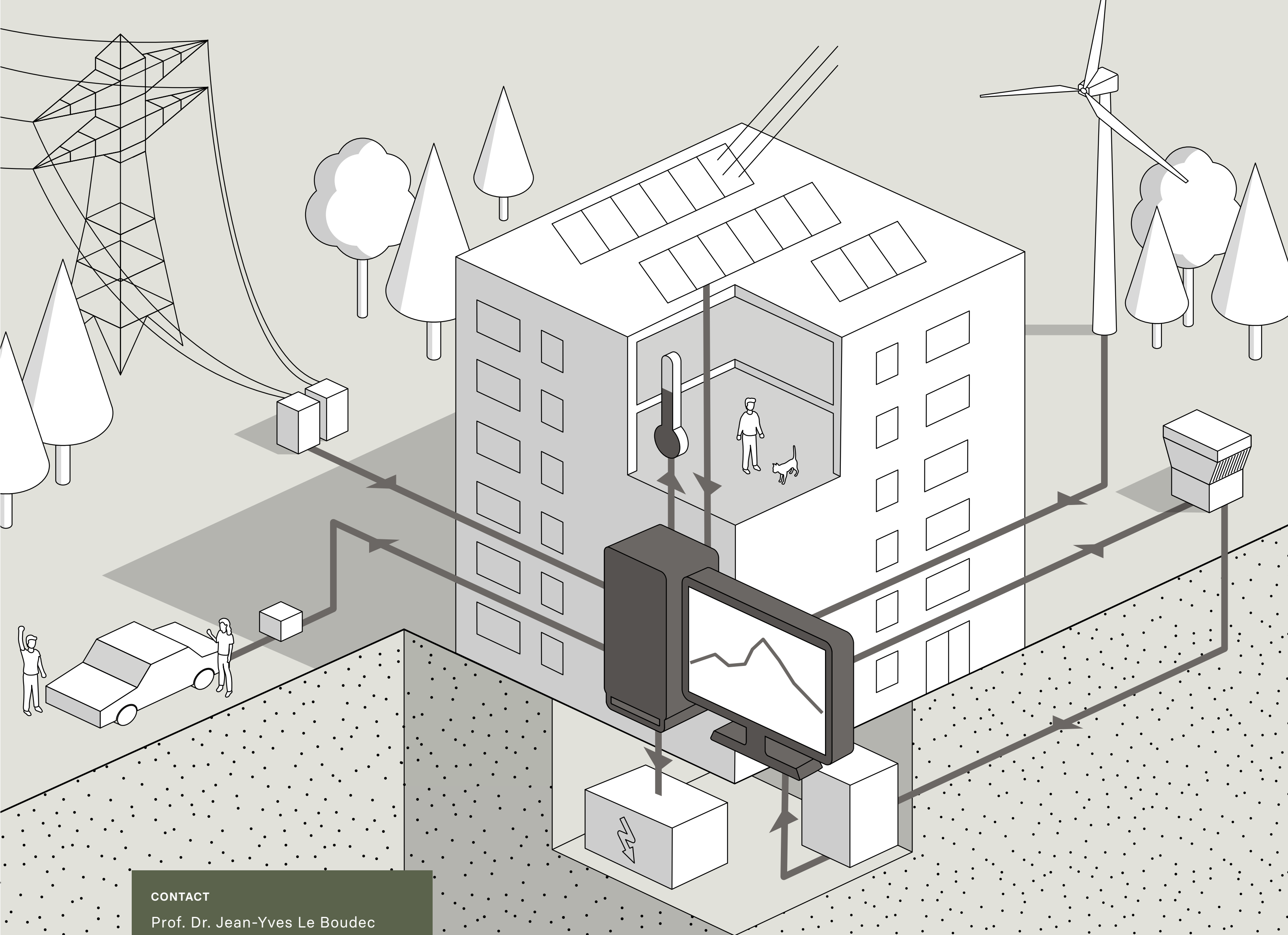
A method developed as part of the NRP «Energy» enables for a building's electricity flow to be regulated in real time, i.e. with response times of less than a second. It integrates different electric resources in the distribution grid such as photovoltaic modules, batteries, fuel cells, heat pumps and charging stations for electric vehicles (see page 51).[37]

34 [New materials for future batteries]

35 [Electricity storage via adiabatic air compression]

36 [Sustainable decentralised power generation]

37 [Software-based real-time grid control]



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PROJECT #energy grids #guidance #supply security

«Software-based real-time grid control»

The increased supply of decentralised renewable energy and the ever greater use of electricity for heating via heat pumps, as well as mobility, increase the risk of capacity bottlenecks in parts of the distribution grids. Strong fluctuations in the provision of solar and wind energy also put grid stability at risk. Storage power plants, which can be switched on and off within a very short time, offer a possibility to overcome this problem. Other conventional methods require costly infrastructure investment, use fuel-driven generators and do not work in real time. **The research team developed and patented a method that allows the electricity flow to be controlled by software agents in real time, i.e. with reaction times of less than a second.** The method, which was implemented on a real scale, integrates different electrical resources in the distribution grid such as photovoltaic modules, batteries, fuel cells, heat pumps and charging stations for electric vehicles. It supports the main grid and ensures the stability of the distribution grid. The team also developed a method for managing the energy consumption of a building and associated equipment to facilitate energy storage capacity across a range of different time scales.

Sector coupling – enhanced opportunities for renewable energy

The linking of different energy sectors (electricity, mobility and heating), which is referred to as so-called sector coupling, will play a key role in the structuring of a sustainable overall energy system. The electrification of the «mobility» and «heating» sectors provides the opportunity increasingly to use renewable energy in these sectors. Sector coupling also makes it possible, where necessary, to convert surplus electric energy into energy forms that are easier to store.

By means of combined heat and power (CHP), cogeneration plants produce both electricity and heat. Settlements situated close by can be supplied with heating via district heating grids. Since the major share of electricity requirements are covered by hydropower and nuclear power plants, CHP plants are not yet widespread in Switzerland. However, the waste heat from nuclear power plants is also used for heating purposes via district heating grids, as is the case, for example, at the Beznau nuclear power facility. Overall, the share of households that consume district heating is relatively small at 4% (FSO 2017). The number of heat pumps, themselves run on electricity, which utilise heat from the ambient air or underground to heat buildings is rising; these systems are now routinely installed in new buildings. A corresponding system is today found in almost one-fifth of all Swiss buildings (FSO 2017). Through the use of new technologies for heat pumps, the capacity and energy efficiency of heating and cooling networks could be increased (see page 38).[38]

The supply of cars that are powered by electric energy has increased greatly in recent years. While initially it was chiefly hybrid solutions that were available, i.e. combinations of electric and petrol motors, there is now an increasing number of fully electric cars on our roads. In countries such as Norway, one in every three newly registered vehicles is already a pure electric car thanks to promotion programmes. In Switzerland, this is the case for less than 2% of new registrations (SwissEnergy & SFOE 2018). An important advantage of electric cars relative to other alternative drive systems (e.g. hydrogen, biogas) is the fact that the electricity supply grid is already in place. For large lorries that operate on medium- and long-haul routes, a focus is being placed on the use of hydrogen drives, while electric drives that utilise batteries are the focus for delivery vans and inner-city buses. The latter could be supplied with electricity via charging stations at the stops.[39]

Power-to-X – storage of converted electricity

The linking of several energy sources enables one medium's storage capacity to be used to balance the variability in the provision of another, for example the storage of highly volatile solar or wind energy. «Power-to-X» includes various coupling variants: power-to-heat, power-to-gas, power-to-chemicals and power-to-liquid. The energy can be stored in the new energy form and later either be consumed in this energy form as required or converted back into electric energy. Heat pumps are one of the power-to-heat technologies. With the help of a heat store such as a borehole heat exchanger or hot water heat store, heat can also be stored over extended periods.

In Switzerland, underground storage offers a potential long-term solution with large capacities that allow for the storage of gas or heat. CO_2 can, if necessary, also be deposited in underground stores. Switzerland's biggest rock formation, which until now had been considered suitable for storage applications, is a salt-impregnated sandstone layer (saline aquifer) located between Olten and Schaffhausen. However, the project «Deep underground heat reservoirs» has determined that it is only suitable for this purpose to a limited extent.[40]

38 [Heat utilisation with solid sorption technology]

39 www.sccer-mobility.ch

40 [Deep underground heat reservoirs]

In the case of power-to-gas technology, water is broken down into hydrogen and oxygen by means of electrolysis. The hydrogen can also be converted into methane and subsequently be fed into the natural gas grid or stored in caverns (SFOE 2017). This enables it to be converted into electric energy at a later time. Seasonal storage using power-to-gas systems represents a possible solution for reducing CO_2 emissions in regions with high potential in terms of renewable resources and for countering the marked seasonal fluctuation between energy requirements and the production of renewable energy at the same time.[41] For example, various power-to-gas systems are in operation in Germany, in particular. In Switzerland, there is still no need for such facilities. However, seasonal storage is also very cost-intensive, which hampers its implementation.

For the power-to-chemicals and power-to-liquid technologies, the hydrogen is used further and synthesised or liquefied into chemical precursors. To date, all of these technologies have exhibited poor efficiency levels. As part of various projects, the NRP «Energy» has contributed to making improvements here (see page 18).[42/43]

41 [Technical evaluation of multi-energy hub systems]

42 [Renewable fuels for electricity production]

43 [Methane for transport and mobility (RMTM)]

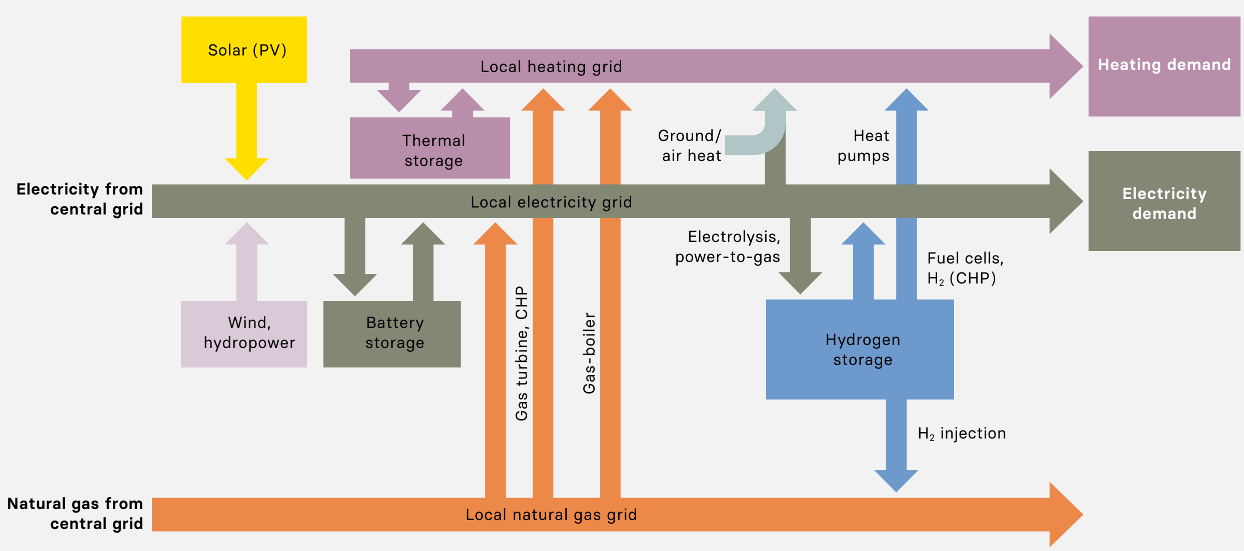


Figure 7

Scheme of a decentralised multi-energy hub system that combines electricity, heat, natural gas and hydrogen in order to provide end consumers with electricity and heating. Here, both renewable (photovoltaic modules) and gas-based (fuel cells, micro gas turbines, boilers) conversion technologies as well as short- and long-term storage technologies (batteries, power-to-hydrogen) are incorporated.

Decentralised multi-energy hub systems – the large-scale linking of energy sources

Where the linking of energy sources is considered for entire urban districts or villages, even greater significance is attached to the system aspect. The bringing together of local components and their joint management generates considerable benefits, especially when they complement one another and redundancies are avoided. The overall optimisation of such systems is not only very challenging due to their complexity, but also in light of data protection. As the project «Control of multi-energy hub systems» shows, decentralised multi-energy hub systems (DMES) allow for costly grid expansions to be avoided.[44] They link various energy carriers and combine renewable and conventional energy sources, conversion technologies and storage technologies. The objective is to minimise the negative environmental impact of the energy supply and to keep costs as low as possible (see figure 7).

Investigation of the economic efficiency of a solar-operated DMES shows that grid-linked systems with photovoltaics and a conversion technology already fare much better than an oil heating system in terms of their economic viability and environmental performance.[45] In the case of stand-alone DMES that are not linked to the grid but which have integrated storage solutions, the costs are currently several factors higher than for systems that are integrated within the grid (Grosspietsch et al. 2018). With rising energy prices and falling costs for the (storage) technologies, stand-alone systems may also become profitable in future. In order to operate DMES in a technically appropriate and economically viable manner, political measures are required, for example in the area of market design or at a communal level in the area of planning.

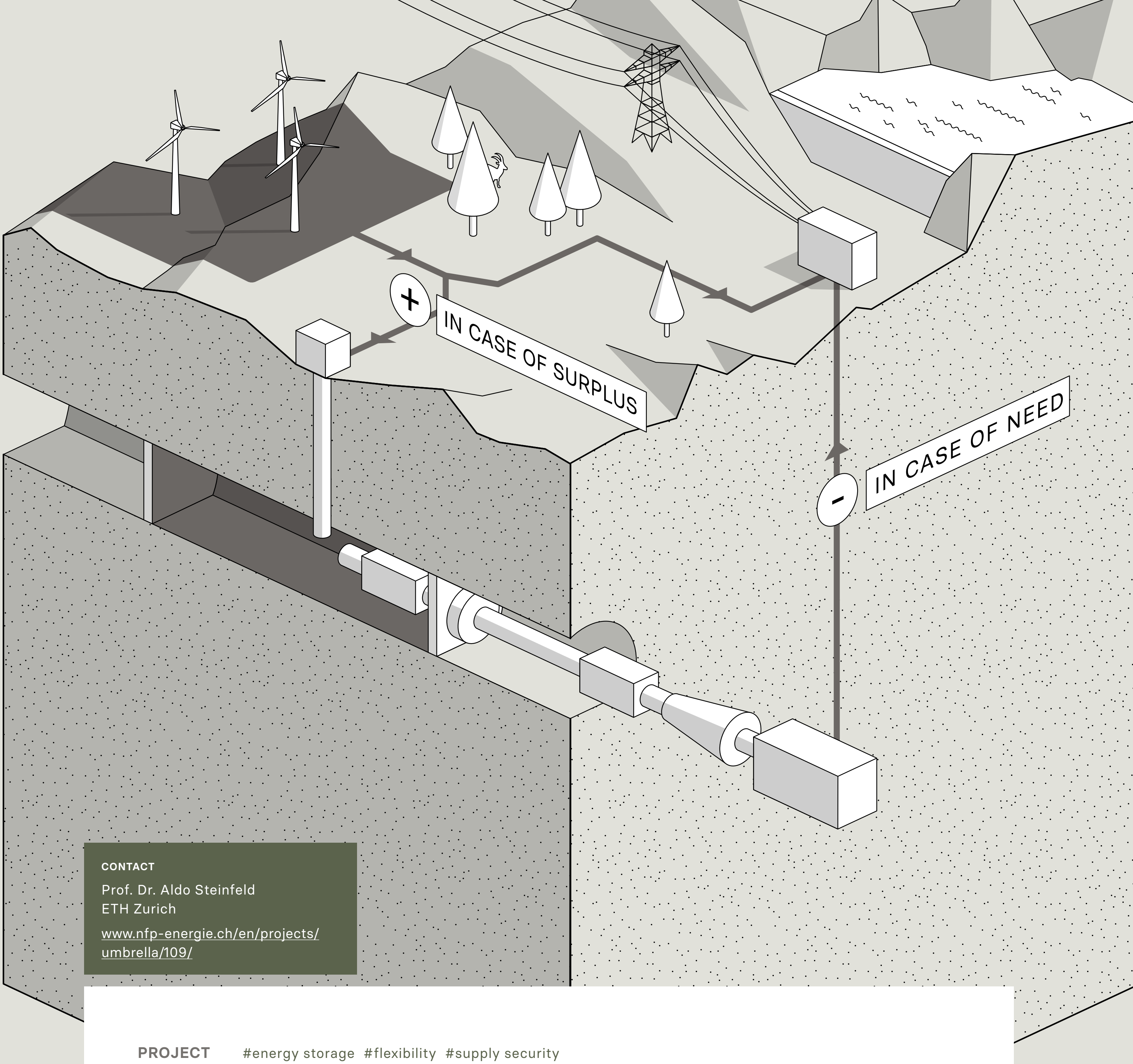
3.4 New financing and business models

The transformation of the electricity system is not only a technical task – it also has a variety of business components. The trend towards decentralisation and decarbonisation in the area of energy provision is creating a need for investment and opening the way for new business models. The need for investment is growing in four areas: increase in energy efficiency, expansion of domestic renewable energy, e-mobility and infrastructure. Examples of the need for infrastructure investment are for the expansion and conversion of electricity grids, especially with the objective of strengthening the distribution grids, for electricity storage and for other energy networks such as gas and district heating grids. The Federal Council put the investment requirements for Switzerland's power plant installations up to 2050 at CHF 193 billion. A large part of this investment is related to renovation that will ensure the continued functioning of the plants. Only CHF 16 billion can be attributed to the increased expansion of new renewable energy (Federal Council 2013).

The traditional business models of current providers are coming under pressure with the transformation of the energy system. At the same time, new opportunities are opening up for both existing and new providers. Alongside prosumers, these also include electronic platforms, which – until now unrelated to the industry – are primarily active in the area of energy trading.

44 [Control of multi-energy hub systems]

45 [Sustainable decentralised power generation]



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PROJECT #energy storage #flexibility #supply security

«Electricity storage via adiabatic air compression»

With the increased use of renewable energy sources, the need for large storage capacity that guarantees grid stability and reconciles supply and demand is increasing. **The research team has demonstrated the technical feasibility of adiabatic compressed air storage power plants with the world's first pilot plant**. Compressed air was stored in a rock cavern in Pollegio near Biasca. Compression generates heat that reaches temperatures of up to 566°C. This is not lost to the environment, but is rather absorbed by an integrated heat accumulator whose storage medium has special physical material properties. Power is generated by expanding the compressed air into a turbine. Thanks to the stored heat, this decompression process eliminates the need for additional heat input, which could increase overall efficiency by up to 74% and cause no additional CO_2 emissions. Further progress is needed before it can be used in practice – particularly with respect to the density of the caverns and the long-term behaviour of the heat accumulator.

Perspectives for hydropower plant operators

The construction and operation of pumped-storage power plants is one of the classic examples of business models that have become less attractive. Until just a few years ago, Swiss energy suppliers could purchase cheap surplus electricity during the night, store this on an interim basis in Alpine hydropower plants, pass the water through the plants' turbines at midday and resell the electricity to domestic and foreign customers at higher prices. The growth of solar energy has scotched this trade strategy. The large supply of solar electricity has especially reduced prices during the sunny hours in the middle of the day, meaning that the price difference between base-load and peak-load electricity, which was interesting for electricity traders, has been eroded. Across Europe, the income figures of pumped-storage power plants have levelled off at around EUR 2 per kWh of storage capacity per year. There is thus no longer an incentive to invest in long-term energy storage.[46] In the project «Investments in hydropower», new instruments were developed that allow robust investment decisions to be taken despite uncertainties. Such new financing instruments reduce the difficulty posed by the fact that investment in hydropower can be used over decades but markets only allow a short-term assessment. To make investment profitable once more, the so-called real option method is recommended. This is based on a time-staggered and flexible investment process. Alongside short-term investments, it also considers future options that are not yet profitable and incorporates these in the planning. The optional investments are deferred.

One option to influence the economic situation of hydropower producers is being discussed in connection with making the water fee more flexible. However, the form that the water fee takes will only play a significant role for a few electricity companies. The impact of the water fee – whether flexible or rigid – is much smaller than the effect of the market price. The higher the market price, the less of a factor the water fee is with respect to profitability – and vice versa. The extreme case, namely the complete eradication of the water fee, would only make a few operators profitable under poor market conditions. In contrast, changes to the water fee will have a much greater impact on the holders of water rights – the cantons and municipalities. This is because water fee income accounts for a large portion of financial resources in numerous municipalities (see figure 8).[47]

Keen interest in the private co-financing of renewable energy

Due to the low-price phase on the electricity market, energy suppliers in recent years have had to suffer financial losses in their core business. Subsequently, there has been a certain shifting of investment forces from large overland plants to regional and urban energy suppliers that were less affected by the changes on the electricity market. The gap that has emerged due to the economic difficulties experienced by large energy suppliers has been filled in part by new players. As a rule, these are individual building owners or real estate companies that finance decentralised solar energy systems. The area is thus detached from the difficulties of the classic energy supply sector. Tenants as well as other households and businesses that do not have the chance to realise their own systems for renewable energy are also showing a keen interest in participating in solar and wind power facilities as small-scale investors. Energy suppliers, solar and wind energy companies and energy cooperatives are able to mobilise such «patient capital» for the achievement of the objectives of Energy Strategy 2050 (Ebers et al. 2019).

46 [Investments in hydropower]

47 [The future of Swiss hydropower]

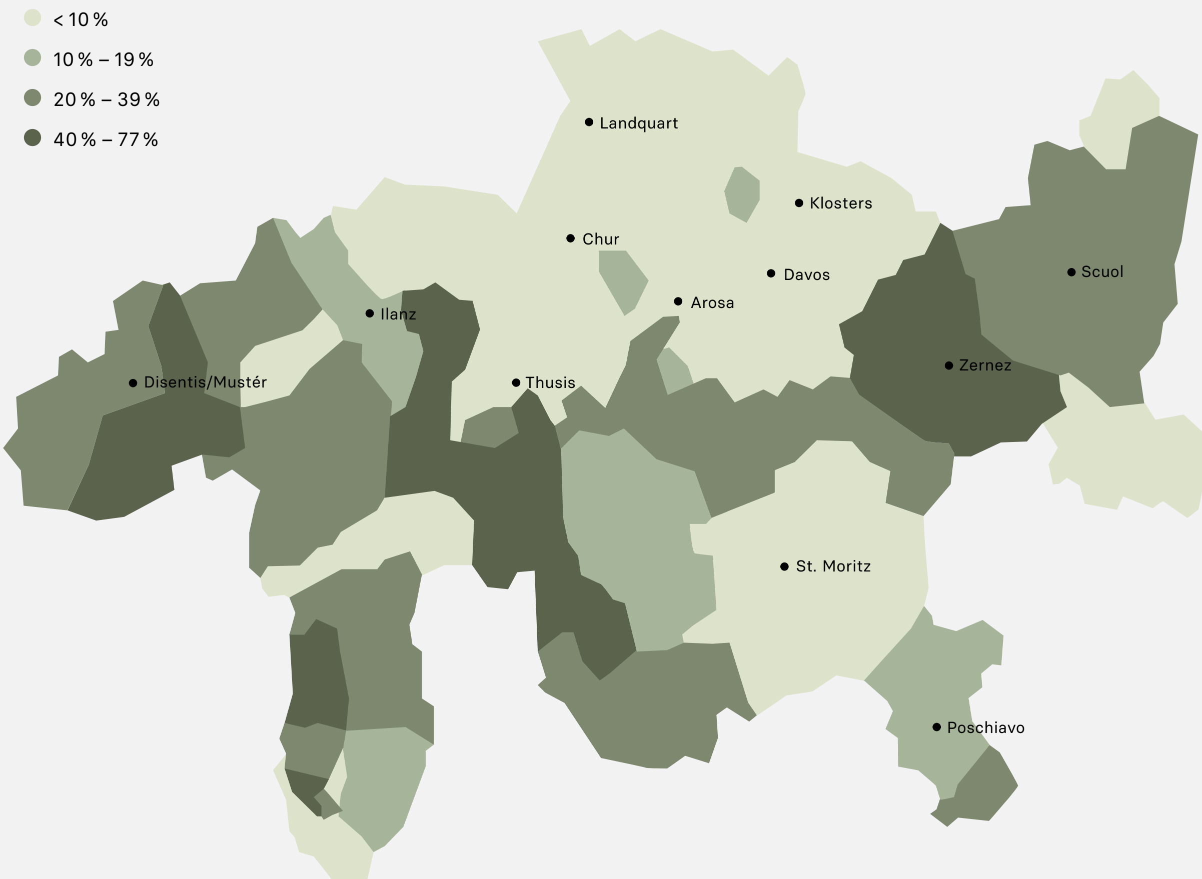


Figure 8

Water fee as a percentage of the financial resources of municipalities in the Canton of Graubünden in 2018. (Barry et al. 2019)

Based on data from the Office of Municipalities (AfG) of the Canton of Graubünden (2018)

Some energy suppliers are developing their existing green power products into participation models that allow customers to acquire stakes in larger-scale solar energy systems. Around 300 energy cooperatives have been established in Switzerland to date. These contribute to the collective financing of solar and wind energy projects. As is the case in Germany, where this organisational model is widespread, there is a close link to the funding policy for renewable energy. Many of the cooperatives were thus created shortly after the introduction of compensatory feed-in remuneration (KEV) in 2009. In recent times, very few of the cooperatives have expanded their capacity unless they have received support at a municipal level.[48] At present, energy cooperatives therefore account for just 1% to 1.5% of solar electricity production. Primarily due to reasons relating to the prevailing market conditions, they are unable to fully exploit their potential.

48 [Collective financing of renewable energy]

Forms of participation such as energy cooperatives are, however, able to increase the population's level of identification with the energy systems. They strengthen the sense of community in the affected regions and in doing so kindle positive momentum for the realisation of further energy projects.

Need for new financing models for the distribution grids

The increasing number of prosumers is having an impact on the financing of the distribution grids: the currently applicable consumption-dependent grid usage tariff means that the financing base will disappear if less electricity is consumed via the distribution grids due to private plants with high levels of self-consumption. Electricity users who are not self-consumers are forced to bear the share of grid usage costs that are lost due to self-consumption. There is cross-subsidisation of self-consumption and thus redistribution (Ulli-Baer et al. 2016). The current framework conditions provide end customers and prosumers with almost no incentive to expand renewable energy, behave in a grid-assistive manner or make investments in storage solutions or DMES technologies. Newly structured grid usage tariffs should create such incentives and assign the relevant costs to their source. It is down to the regional distribution grid operators to develop corresponding business models.[49]

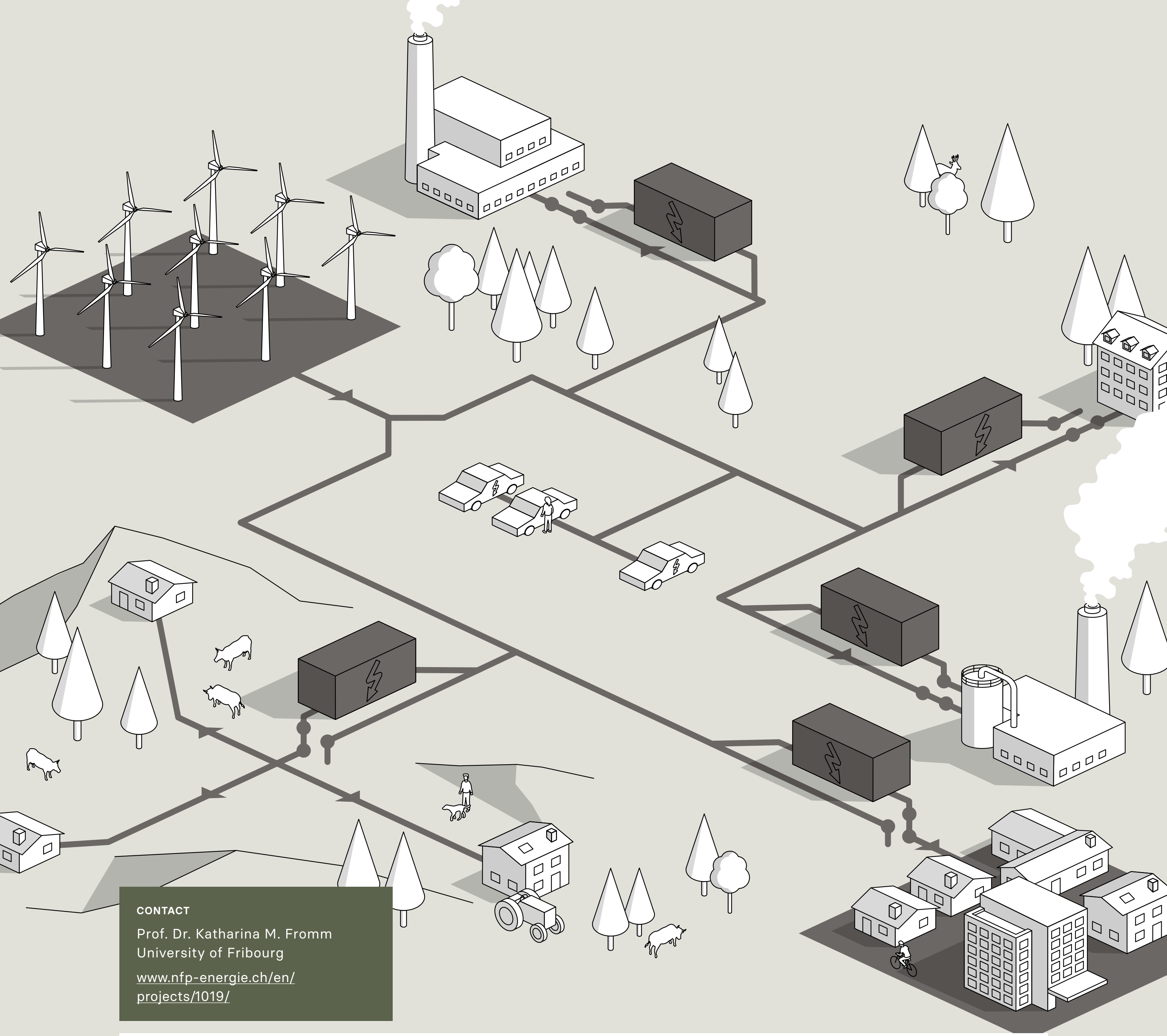
Investment alternatives and barriers

The individual investor types act according to very different decision-making criteria and processes (Salm et al. 2016). The capital costs of the various investors differ depending on the alternative investment opportunities with which they compare energy investments. In the current low interest rate environment, pension funds, for example, can in some cases finance investments at lower costs than energy suppliers (Salm & Wüstenhagen 2018). Private investors, on the other hand, often make their decisions less analytically and also incorporate intuitive aspects in their decision-making process, as shown by the project «Energy reduction potential of elderly people's households».[50]

The current low interest rate environment tends to be beneficial for the financing of investments in energy efficiency. However, energy efficiency has to compete with other investment options (more living space, better standard of equipment, etc.) for the attention of investors. Targeted offers such as Minergie mortgages, or financing offers for solar energy systems, can increase the likelihood of such investment being realised. There is also the question of how in rented residential buildings the costs and benefits of energy investments can be split between landlords and tenants. This issue represents a considerable obstacle for investment in energy efficiency in the building sector.

49 Synthesis on the main topic of «Market Conditions and Regulation» of the NRP «Energy». SNSF.

50 [Energy reduction potentials of elderly people's housholds]



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PROJECT #energy storage #flexibility #mobility

«New materials for future batteries»

The provision of electricity from renewable sources does not necessarily coincide with demand. Excess energy produced must therefore be stored. Metal-air batteries are ideal battery stores. They are able to store a great deal of energy in little space. Their energy density is 10 to 30 times higher than that of conventional accumulators, i.e. almost as high as that of petrol. The research team developed new components for lithium-metal high-energy accumulators – molybdenum (IV) sulphide (MoS_2) membranes and crown ether-based ionic liquids – that are superior to the components currently available on the market. They improve the charge/discharge cycle and increase safety at the same time. These new materials can be used in a wide range of applications. **Further developed, the new materials could also be used in batteries for electromobiles.**

3.5 A sustainable energy system

The objectives of sustainable development demand that the energy system also meets the high, globally accepted sustainability requirements with respect to the three dimensions of environment, economy and society to the greatest possible extent. Specifically, this means «reducing climate change», «efficient use of energy and other resources», «minimal impact on the health of people and the ecosystem», «affordable costs», «supply security» and «social acceptance».

With the «Sustainability Assessment for Energy Technologies», the scientific world has developed a method based on multi-criteria decision analysis (MCDA) over the past two decades that is suitable for the comparative, quantitative assessment of new technologies and their effects on sustainable development (Hirschberg & Burgherr 2015). This approach is in line with the UN's Sustainable Development Goals (SDGs). It only applies to those 17 goals and 169 indicators of the SDGs that are highly relevant to the energy system. Goals relating to poverty, hunger and gender aspects are not taken into account, for example.

State-of-the-art sustainability assessment

The ranking of various technologies or solution alternatives with respect to their impact on sustainable development is generally determined in six steps:

1. Selection and description of the objects to be compared (technologies/solution alternatives);
2. Determination of target criteria and associated indicators;
3. Quantification of indicators;
4. Weighting of indicators;
5. Overall assessment of the objects to be compared;
6. Sensitivity analysis for varied weightings of the indicators.

In the EU NEEDS project (New Energy Externalities Development for Sustainability), a list of assessment criteria was drawn up as part of an effort that is still unrivalled in terms of its comprehensiveness (see figure 9). This list enables a comparative assessment of the sustainability of electricity generation technologies and the corresponding value chain (Ricci et al. 2009). In the latest research work, supply security has been added as a fourth dimension alongside the three classic sustainability dimensions.

For the quantification of indicators (step 3), various approaches are generally applied. In the spirit of sustainability, the quantification of environmental indicators is based on life cycle assessments (LCAs). For social indicators, and especially for the indicators «damage to health» and «air pollution», the so-called «impact pathway approach» has also proved its worth (Friedrich & Bickel 2001). The quantification of risks due to hypothetical, severe accidents is based on real empirical values or occasionally on «probabilistic safety assessments» (PSAs). The economic indicators are assessed on the basis of life cycle cost assessments and the other indicators on the basis of data from the energy sector or expert opinions.

	Criterion
Environmental dimension	**Resources**
	Energy resources
	Mineral resources (ores)
	Climate change
	Impact on ecosystems
	Impact from normal operation
	Impact from severe accidents
	Wastes
	Special chemical wastes stored in underground depositories
	Medium and high level radioactive wastes to be stored in geological repositories
Economic dimension	**Impact on customers**
	Price of electricity
	Impact on overall economy
	Employment
	Autonomy of electricity generation
	Impact on utility
	Financial risks
	Operation
Social dimension	**Security/reliability of energy provision**
	Political threats to continuity of energy service
	Flexibility and adaptation
	Political stability and legitimacy
	Potential of conflicts induced by energy systems
	Necessity of participative decision-making processes
	Social and individual risks
	Expert-based risk estimates for normal operation
	Expert-based risk estimates for accidents
	Perceived risks
	Terrorist threat
	Quality of residential environment
	Effects on the quality of landscape
	Noise exposure

Figure 9

Assessment criteria and indicators according to NEEDS (Hirschberg et al. 2008)

Instead of multi-criteria decision analyses, cost/benefit analyses in which all indicators are quantified in terms of their monetary value are also used. However, this approach is the subject of controversial debate amongst specialists as some indicators, and especially those belonging to the social dimension, are extremely difficult to express in monetary terms.

With the help of multi-criteria decision analysis, very sophisticated sustainability assessments have been conducted in the energy sector over the past ten years in Switzerland as well as in Europe and China (Roth et al. 2009; Schenler et al. 2009; Volkart et al. 2017). Thanks to the variety and breadth of these studies, it is reasonable to conclude that multi-criteria decision analysis and the indicators presented in Figure 10 represent an appropriate methodological basis for comparative assessments of possible responses to different issues relating to the sustainability of the energy system.

Methodological approaches in the NRP «Energy»

For collaborative projects in the sense of a cross-sectional task, the call for proposals for NRP 70 had stipulated that the economic and social advantages and disadvantages of the individual value chains must be quantified – with the application of proven analysis and evaluation methods. Around half of the total of 15 joint projects complied with this requirement as did an independent sub-project on the subject of sustainability. The others integrated the corresponding statements in their final scientific report. All researchers aimed at a comparative analysis of the technologies developed in their joint project with conventional concepts. To this end, they used different methodological approaches:

- a holistic sustainability assessment based on a benefit analysis incorporating the three dimensions of environment, economy and society was performed in the joint projects «The future of Swiss hydropower»[51], «Renewable energy for electricity production»[52] und «Heat utilisation with solid sorption technology»[53].

- Two joint projects used life cycle analyses (LCAs): in the joint project «SwiSS solid-state SiC transformer»[54] for the entire transformer on the basis of a list of 19 environmentally relevant indicators, in the joint project «Next generation photovoltaics»[55] for the social dimension of the process steps «raw material procurement» and «assembly» of the new perovskite tandem solar cell as well as for the environmental dimension of the new solar cell and its integration into the grid. In the latter joint project, the LCAs were supplemented with profitability analyses.

- For the joint projects «Waste management to support the energy turnaround»[56] and «Low energy concrete»[57], the sustainability programme is omnipresent in all sub-projects. In methodological terms, focus is placed on life cycle analyses (LCAs) for the sustainability assessment of developed products and strategies. In the joint project on waste management, they were supplemented by analyses of life cycle costs and transformation paths.

- In the other joint projects, the sustainability of the developed technologies was dealt with only very selectively, with a predominantly qualitative approach being adopted that was not very systematic.

51 [Hydropower sustainability]
52 [Sustainability of methanation]
53 [Sustainability of adsorption heat pumps]
54 [SiC solid-state transformer in the grid]
55 [Sustainability of PV systems]
56 [Waste management to support the energy turnaround]
57 [Low energy concrete]

Sustainability assessments in the NRP «Energy»

With respect to the results of the sustainability assessments, the following six statements stand out:

- In terms of integral sustainability, adsorption heat pumps perform significantly better than conventional heat pumps with compressors, both for use in a single building and for a decentralised multi-energy hub system (DMES).[58]

- Hydropower is generally considered to be sustainable. Even negative profitability and the sector's undisputed adverse environmental impact are clearly offset by the sum of the other indicators.[59]

- With regard to the methanisation of CO_2 from cement production, of the three investigated applications «methane in the gas grid», «building heating» and «hydrogen for vehicles» only the latter proves to be more sustainable than current solutions. However, this is only on the condition that all excess electricity from renewable energy can be used for electrolysis. In terms of economic efficiency, all three paths perform significantly worse than fossil methane combined with CO_2 certificates.[60]

- The application of the new perovskite tandem solar cell with heterojunctions for building-integrated solar modules offers great potential in terms of integral sustainability. In order to achieve this, further efforts are needed in terms of working conditions, especially in China, as well as with respect to durability and performance degradation over time.[61]

- The sustainability of the semiconductor-based SIC solid-state transformer is significantly worse than that of conventional transformers. Furthermore, it is unsuitable for use in the electricity distribution grid at the lower distribution level (grid level 6) as had originally been planned. Its great advantage lies in the fact that it allows a significantly higher feed-in of intermittent solar and wind power without grid reinforcement.[62]

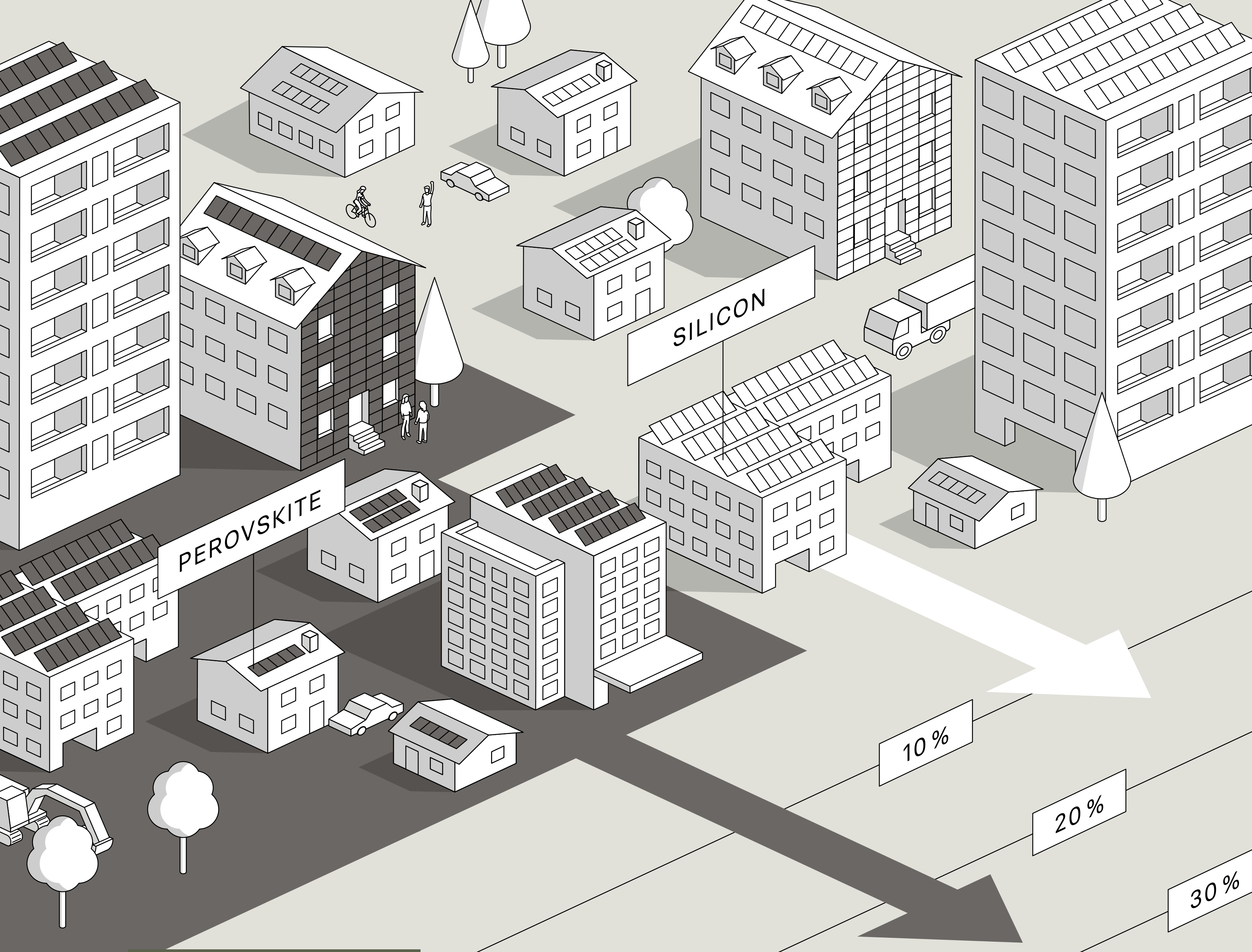
- The production of aviation fuel from biomass could be made sustainable in Switzerland. In economic terms, however, it falls a long way short of fossil kerosene.[63]

Within the framework of the NRP «Energy», no complete and detailed multi-criteria decision analyses were carried out, as most of the research work still has a relatively low degree of technological maturity. Numerous important indicators are therefore still unknown or can only be estimated very vaguely. It is also clear that no technology fully meets all sustainability criteria, as each technology has specific advantages and disadvantages. It is also highly likely that this will never by the case. A certain trade-off is therefore unavoidable in making any decision to opt for a particular technology.

Necessary weighing of interests

As a rule, all energy infrastructure projects – whether large or small, urban or rural, renewable or non-renewable – must take account of a wide range of requirements and interests. This often results in conflicts of objectives with other policy areas such as the environment, agriculture, civil aviation and national defence. Many of these conflicts can be identified and resolved on the basis of a clear planning process. Some, however, are of a fundamental nature because they concern issues which have been assigned equal value under federal or constitutional law. The Energy Act, which has been approved by the electorate, attributes a national interest to certain energy installations for the use of renewable energy that is equivalent to other

58 [Sustainability of adsorption heat pumps]
59 [Hydropower sustainability]
60 [Sustainability of methanation]
61 [Sustainability of PV systems]
62 [SiC solid-state transformer in the grid]
63 [Sustainability of bio fuels]



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PROJECT #photovoltaics #energy efficiency #building

«Perovskites for solar energy»

For some years now, perovskite minerals have been regarded as the future hope for solar cells. Due to their composition and lattice structure, they have remarkable properties such as good light absorption and good charge carrier mobility, which are central to the generation of electricity. They are also easy to process and suitable for chemical synthesis. **Thanks to an improved synthesis, the research team succeeded in increasing the efficiency of perovskite-based photovoltaic cells to a record level of 21%, which has since been surpassed again.** The team was also able to improve the stability and thus the long-term behaviour of the cells. Finally, it revealed new behaviours of charges that could pave the way for innovative applications of perovskites forlight-emitting devices.

legally protected national interests (e.g. landscapes of national importance). In concrete terms, however, a decision on which interest prevails must be made on a case-by-case basis (Federal Council 2012). Should such an energy project touch on a different national interest, both have equal rights for the time being and the competing interests must be identified, evaluated and carefully weighed up against each other in accordance with the Spatial Planning Act (SPA).[64]

This balancing of interests is based on an integral sustainability assessment that takes into account the three dimensions of environment, economy and society in an even-keeled manner, comparing the new solution – or rather different alternatives – with the current situation. How many and which indicators have to be taken into account and how they are weighted depends greatly on the specific case. It is crucial that the choice and quantification of indicators are carried out by experts. However, the conclusions must be drawn through dialogue between stakeholders. This means that all relevant stakeholders must be involved in the early stages of this process.

3.6 The human factor

In order to advance the transformation of the energy system, the requirement is not only for technologies to meet sustainability criteria. It also requires decisions to be taken by individual people in their various roles. The NRP «Energy» has dealt intensively with the social aspects that guide activities in the direction of a sustainable energy system.

64 Art 3. Spatial Planning Act (SPA)

From knowledge to will and action

If a person is to act in a certain way, they must be motivated to do so and have the necessary opportunities and abilities. Where these conditions are met, the chances are good that people will also turn their intentions into action. Motivation, opportunities and abilities can be addressed in a simplified manner with the keywords «knowledge», «will» and «action».

To enable people to make their contribution to improving energy efficiency or sufficiency (see page 66), they require knowledge about the problems relating to energy consumption. In some cases, however, there are considerable knowledge gaps in the population.[65] For example, less than half of the Swiss population knows how high their electricity bill is (Filippini et al. 2018). A surprisingly high share of 20% of the population also do not believe that scientifically proven global warming is actually taking place (see page 68).[66] If progress towards a sustainable energy system is to be achieved in such an environment, information and awareness-raising campaigns must take deliberate account of where the specific target groups find themselves in the continuum between «knowledge», «will» and «action» (see page 27).[67] It also needs to be communicated in a convincing manner that a large part of the energy-efficiency potential can be tapped without sacrifice or loss of comfort: greater energy efficiency does not mean less comfort![68]

Social practices and norms play a considerable role in determining individual desires and actions. This is underlined by several projects from the NRP «Energy». One promising approach turns out to be the incorporation of behavioural change in the practices of existing communities such as sports clubs and local associations.[69] For example, it was found that people not only make use of carpooling options because in doing so they can

65 [Acceptance of renewable energy]
66 [Soft incentives and energy consumption]
67 [Sustainable lifestyles and energy consumption]
68 [Understanding household energy consumption]
69 [Promoting energy-sufficient behaviour in cities]

make a contribution towards a more sustainable form of mobility. At least as important is that carpooling is accepted as an attractive means of transport by others in their environment.[70] As regards «will», role models therefore assume an important role in all social groups.[71] Developing an isolated phenomenon into a broad social trend can thus be supported with appropriate role models. As multipliers, they increase credibility, in particular, and help to break down reservations and transport social norms.

Many people also lack the know-how to behave in an energy-efficient manner. Here, individual willingness to change our behaviour largely depends on how great the required change is and which areas of life this affects. The acceptance of energy-efficient approaches and products grows if people can gain experience with them themselves. For example, people from cantons that are home to many small hydropower plants also show a particularly high level of acceptance for this technology (Balthasar & Strotz 2017).[72]

Energy and environmental issues are not a matter of high priority for many Swiss citizens. Instead, they place an emphasis on matters that are related to personal quality of life, such as health, well-being, convenience, connectivity, comfort and security. As a consequence, the more energy-conscious behaviour is linked to an additional benefit that concerns personal quality of life, the greater the effect of an energy campaign. In this way, an aspect which has positive associations is placed in the spotlight.

Sufficiency – voluntary restrictions

Sufficiency represents an important strategy towards achieving a more sustainable energy system. The reduction in energy use that this entails can be achieved in a variety of ways, including the following (Kaufmann-Hayoz et al. 2001, 2006):

- forced forgoing by law, e.g. the banning of lightbulbs;
- suggested forgoing via pricing, e.g. petrol taxation;
- suggested forgoing via infrastructure circumstances («nudging»), e.g. due to the fact it takes longer to reach your destination by using the lift than the stairs (Thaler & Sunstein 2009);
- self-imposed forgoing through personal undertakings for yourself or as a member of a community, e.g. an association proposes that members travel by bike;
- limitation of use for moral reasons, e.g. because there is an understanding that resources may not suffice for everyone;
- limitation of use for «health reasons» for the benefit of yourself and others, e.g. deciding to travel by bike because it keeps you fit, is fun and reduces pollution for everyone (Schweizer-Ries 2009).

With the exception of the forced forgoing of use by law, all measures are of a voluntary nature. The heart of the sufficiency approach revolves around finding the right balance, i.e. enjoying a successful life and happiness without adversely affecting others (Küstenmacher & Seiwert 2004). The basic principle is to examine the active decisions of people, organisations or states with respect to what they really require in terms of space, room temperature, warm water, lighting intensity, etc. and to implement the relevant usage accordingly.

70 [Sharing economy: hype or promise?]
71 [Sustainable lifestyles and energy consumption]
72 [Acceptance of renewable energy]

Sufficiency does not require people to go without what they need, but rather to voluntarily sacrifice what is not essential (Stengel 2011). This does not result in any real limitations with respect to services, but rather in terms of resource utilisation. Resources that are already available, for example surpluses from the provision of renewable energy, can be used free of problems. What is required is intelligent usage behaviour, i.e. using energy when it is available in abundance (load shifting) (Lange 2019). The sufficiency approach also works in the area of efficiency by preventing improvements in technology from being offset or even counteracted by additional use (rebound effect).

Sufficiency policy pursues four approaches: enable (structural), encourage (informative and appellative), engage (through participation and governance) and exemplify (creating positive examples and competitions) (Linz 2017; Schneidewind & Zahrnt 2013; Sachs 1993). These approaches are not regarded as «either or», but rather as «both». They are thus all required in order to achieve comprehensive effectiveness. In concrete terms, suggestions in planning – for example in the field of mobility – can contribute to promoting sufficiency by encouraging activities such as working, shopping or relaxing in an individual's immediate vicinity. Other possibilities are offered by demonstrating the advantages of reduced consumption.

Break habits

The greatest part of our everyday behaviour follows ingrained routines. Changing habits of this kind is considered to be very difficult. Several research projects therefore emphasise that ensuring the compatibility of a desired, environmentally friendly behavioural trait with people's everyday habits is one of the most important success factors of campaigns and activities.[73/74/75] Significant life events such as marriage, the birth of a first child or a move to a new home can serve as possible starting points for breaking down undesirable deep-seated behaviours. However, people also need to be addressed in line with the phase in life in which they find themselves when taking their decisions («knowledge», «ability», «action») (see page 27).[76]

Organisations that do not specialise in the energy sector perform pioneering work by testing original methods aimed at supporting the energy turnaround. The Swiss Homeowners' Association (HEV) has conducted interactive workshops with the objective of encouraging older homeowners to plan their future living and housing situation better. Through greater building density, moving to a smaller flat or implementing energy-efficient renovation, there is potential to save a great deal of energy in older people's homes. With these strategies, up to 4% of the annual energy-saving objectives stipulated under Energy Strategy 2050 in the area of «space heating» could be achieved.[77] The Terragir assocation became active at a completely different level: it launched a competition that saw participants try to wear new jeans for as long as possible without washing them. This initiative enabled the participants to scrutinise their washing habits and thus their electricity consumption. It also showed that social learning in the form of competitions or demonstrations can help to change established practices (Sahakian & Bertho B. 2018).

73 [Sharing economy: hype or promise?]

74 [Exploring ways towards societal consensus]

75 [Understanding household energy consumption]

76 [Sustainable lifestyles and energy consumption]

77 [Energy reduction potentials of elderly people's households]

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www.nfp-energie.ch/en/projects/943/

PROJECT #incentives #acceptance #behaviour

«Soft incentives and energy consumption»

Not only money, but also non-material motivations such as social norms, symbolic rewards and changes in generally-accepted «standard» behaviour – so-called soft incentives – can influence energy-saving behaviour. The research team combined field tests with longitudinal surveys and intervention studies to find out what influence the soft incentives have in real life. In particular, the energy consumption data of more than 200,000 households, over 7,000 small and medium-sized enterprises (SMEs) and 400 energy-intensive companies were evaluated. They were informed by their electricity provider that the electricity supplied would in future come from renewable sources as standard.

Those who did not want this standard package had the option of switching to conventional electricity. The introduction of this standard had a massive effect: previously, well over 90% of all households and companies purchased conventional electricity. Now, around 80% accepted the new standard and purchased green electricity. Acceptance of the new standard was only slightly dependent on electricity consumption and was very stable over time. Fewer than 5% of customers switched back to conventional electricity within four years. For the researchers, it is clear that **establishing environmentally friendly behaviour as the standard proves to be a successful approach in everyday life.**

High level of acceptance required in the Swiss political system [78]

Due to the country's federal structure and system of direct democracy, it is especially important in Switzerland that energy-relevant objectives and measures enjoy broad acceptance. The ability of the Swiss population to call for a referendum on a parliamentary decision allows them, for example, to force votes and, depending on the result, to veto the parliamentary decision in question. This applies not only to the basic orientation of energy policy, but also to the implementation of energy policy at a national, cantonal or municipal level. Voting success is dependent on the approval of important parties and stakeholder organisations. Only if these bodies back the authorities' objectives can majority support be gained among voters.

Acceptance cannot be forced upon people, but must rather be gained. The provision of credible and transparent information forms the basis for doing so. Building on this, the population and economy need to be able to recognise both the overall advantages of a plan and individual benefits. It can be seen, for example, that headway is made in terms of the expansion of renewable energy where the local population benefits from this and also perceives this to be advantageous (Zoellner et al. 2012). The most success is promised by approaches that focus on people's local and personal environment. Last but not least, acceptance is a matter of trust – and this needs to be developed. There is also the question, however, of what form of acceptance needs to be achieved. Will passive approval suffice or is active support required? Passive acceptance leads to approval, while active acceptance means support. Sometimes it is enough if the relevant stakeholders do not have opposing views of a plan. Sometimes it is necessary for the relevant parties to become actively involved in the design process or for them to express their support explicitly for a project or a measure.

Direct democracy is largely responsible for ensuring that things only move forward in the Swiss political system with «oversized majorities» (Linder et al. 2017). A political control instrument such as an energy tax can only be introduced and a new energy plant can only be realised if a broad political majority supports these matters and no strong opposition forms. While acceptance requirements vary depending on the project in question and the situation at hand, they are generally high.[79] For the planning and designing of an energy-policy project, it is therefore necessary to identify and incorporate the relevant stakeholders and their role in the specific process. Where this is done, it may be possible to generate broad acceptance for the process and the likelihood of opposition can be reduced.

Switzerland's political system generally does not support large and comprehensive reforms. However, compromises that have been made enjoy a high level of support and therefore provide the chance that the next step can also be taken. A broadly supported compromise has a better chance of success as it typically integrates the aforementioned factors, increasing the level of acceptance enjoyed by a project. A compromise will likely also be key, however, in order to gain acceptance from a majority of citizens despite significant aversion to the costs incurred for a project.[80] The long-term nature of Energy Strategy 2050, which was approved by Switzerland's voters, is a success factor that also has to be taken into account during the specification of the implementation process. For example, stable framework conditions over the long term are decisive when it comes to the economy's willingness to innovate. Generally speaking, the population also tends to be willing to approve changes that contribute to the achievement of a long-term goal that has been politically accepted. This is demonstrated by examples from the areas of transport, migration, European and energy policy.

78 Synthesis on the main topic of «Acceptance» of the NRP «Energy». SNSF

79 [Acceptance of renewable energy]

80 [Modernising waste management]

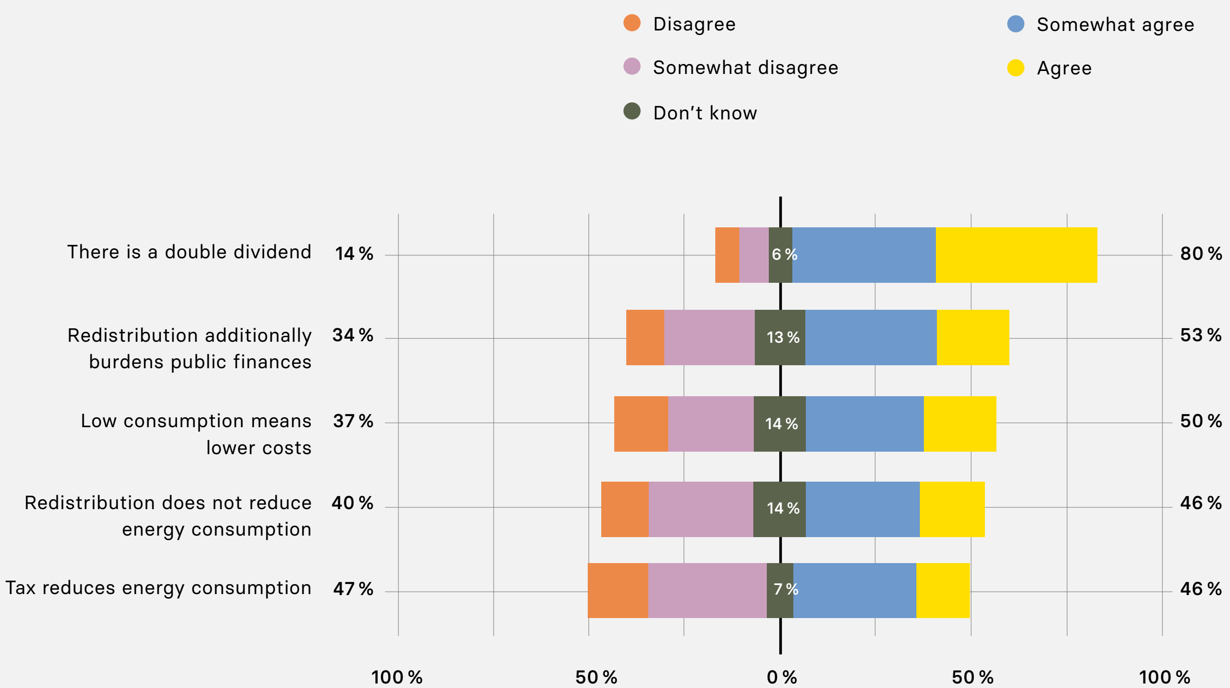

Figure 10

Attitudes towards environmental taxes.
Degree of acceptance of environmental taxes and the use of other means.
(Stadelmann-Steffen et al. 2018).

Consumers at the ballot box

People in Switzerland apply different patterns of thought in their roles as consumers and voters. Individuals evaluate energy policy measures according to different criteria, depending on whether they assess their effect on their personal lives or whether they think about it in their role as voters.[81] Of course, both roles are not strictly separated from one another. When individuals make a decision on an energy-policy vote, the extent to which the bill appeals to them as consumers may well be important. The formula is simple: the higher the costs, the lower the likelihood they will approve the proposal as voters. Interestingly, this pattern can be seen both for individuals towards the right of the political spectrum, who do not attach much importance to the energy transformation, as well as for those on the left and green voters.[82]

A very significant factor in how future energy policy is assessed is the expected benefits of a measure, its feasibility and its appropriateness for various stakeholders. In the case of many measures under discussion, it is these key criteria, that citizens do not believe are met. This is often due to the fact

81 [Exploring ways towards societal consensus]

82 [Acceptance of renewable energy]

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PROJECT #financing #steering / promotion #economy

«Environmental tax reform and endogenous growth»

In order to achieve the goals of Energy Strategy 2050 and to reduce greenhouse gas emissions massively, the existing funding policy can be supplemented or replaced by a steering system. In the project «Ecological tax reform and endogenous growth», the researchers examined the influence of a steering system on Switzerland's economic strength. To this end, they calculated the effects using a computer model calibrated to Swiss conditions. The research team concludes that Switzerland would also benefit economically from an environmental tax reform. **To reduce the burden of taxes on electricity and fuels, companies would invest more resources in innovation and more efficient processes.** These would stimulate economic growth and thus offset the higher production costs due to taxes. Politically, it is desirable for taxes to flow back to the various social groups in an appropriate and fair form; to this end, the research team has used the model to calculate various scenarios: during the transition to a steering system, consumption growth would be slightly lower than for a development without steering. The increased quality of life thanks to a cleaner environment, however, has not been taken into account in this cost-focussed assessment.

that they lack knowledge of their own energy consumption. Furthermore, they are also not sufficiently aware of the effects of many of the measures on which they decide. For example, they are predominantly, and incorrectly, of the view that an environmental tax will not reduce energy consumption if the tax revenues are redistributed to the population (see figure 10). Against this background, it comes as no surprise that energy-policy bills often fail at the ballot box. Why should someone vote in favour of a measure if it causes costs and they do not believe in its effect?

Design of energy plants and the decision-making process – important basis for acceptance

A majority of the Swiss population prefer renewable energy to fossil or nuclear energy as is shown by various projects of the NRP «Energy» and their clear approval, as sovereign body, of the new Energy Act. Nevertheless, resistance often emerges in the case of specific projects for renewable energy such as wind energy and small hydropower plants. This local opposition was for a long time explained by the «not in my backyard» (NIMBY) phenomenon: for example, while citizens like wind energy and wind turbines as a general rule, selfish reasons mean they do not want to see wind turbines pop up near to them. However, the reasons for local opposition are much more varied. For instance, part of the population are sceptical about the technical infrastructure linked to renewable energy, including wind turbines, geothermal energy plants and high-voltage power lines, irrespective of where they are located.[83]

The project «Energyscapes» shows, however, that the acceptance of infrastructure for renewable energy provision is closely linked to the landscape type, the combination of energy plants and how an area is already utilised. The more untouched a landscape is perceived to be, the greater the rejection of energy infrastructure. The best-rated solution is the pure but moderate utilisation of solar energy on roofs and facades, which enjoys even better acceptance than a landscape devoid of energy infrastructure (see page 44).[84] The result corresponds to the findings on the acceptance of overland power lines. If existing overhead power lines are converted with the objective of increasing their capacity, they are better accepted than new power lines.[85]

It is usually the «hard» technical components such as size and location as well as a measure's impact on nature that represent the main reason for the construction of new systems being rejected. The specific design of a project is therefore decisive in terms of whether citizens support local infrastructure projects. The greatest support is enjoyed by those projects that are planned at sites where people have already made an impact or modification, for example military compounds or areas surrounding a very busy road (see page 44). On the other hand, no further strain should be placed on residential zones, forests, woodland perimeters and agricultural land that serve as settlement and relaxation areas or natural habitats. Moreover, power plants – if they are already being built – should make a considerable contribution to the energy supply, while their impact on nature should be minimised.

Alongside the infrastructure project itself, the co-determination process is also relevant: in the direct democratic context of Switzerland, the pure provision of information is not enough from the perspective of the population. Real co-determination, together with a vote, is the only means of creating acceptance for the process. The transition from an informal co-determination process to formal proceedings proves to be a challenge, however. It must also be ensured that those aspects jointly determined in a vote can actually be realised and not be put into question once more via rights of appeal. Finally, the importance of the cost factor is also confirmed at a local level.[86]

83 [Acceptance of renewable energy]

84 [Energyscapes]

85 [Hybrid overhead power lines for Switzerland]

86 [Acceptance of renewable energy]

3.7 Political steering – from objectives to implementation

All energy regimes require specific regulations (see chap. 2.4). At present, the Swiss energy system is governed by energy-source-specific legislation. Further influences not only include other federal legislation (e.g. from the areas of spatial development and environmental policy) which plays a key role in shaping the implementation of energy policy, but also cantonal regulations, especially in the building sector. Ultimately, alongside the federal government, it is chiefly the cantons and municipalities that are also responsible for the implementation of acts and ordinances.

In order to realise the energy transformation, it is necessary to implement measures, conduct projects or introduce technologies. Political steering can stimulate, simplify or facilitate these developments. Steering instruments are measures used by state players to achieve political objectives (Howlett 2005). The transformation is changing the position of the various stakeholders as well as the objectives and forces of the energy system. Regulatory changes are thus also required.

Demanding requirements for politicians

From a political standpoint, the objectives for the transformation of the energy system in Switzerland have been defined with Energy Strategy 2050. With the approval of the Energy Act and the associated legislative changes by Switzerland's voters, these objectives have been anchored in law. For example, the Energy Act aims to ensure the economically viable and environmentally friendly provision and distribution of energy, the economic and efficient use of energy and the transition to an energy supply system that is increasingly underpinned by the use of renewable energy. The starting point of the transformation is formed by the phasing out of nuclear energy, a measure which is supplemented by international climate protection commitments. The emission reductions required under the Paris Agreement are expected to be legally defined as part of the current total revision of the CO_2 Act. They outline the path to phasing out fossil energy sources. A sustainable energy system must, however, also fulfil other requirements (e.g. affordability) that are only anchored to a certain extent in Energy Strategy 2050 and the legal provisions based on this.

A variety of implementation instruments – from bans to incentives

The range of political instruments is very broad. The strongest form are guidelines and bans (regulative instruments) that may possibly stipulate or restrict stakeholder behaviour in a very specific manner. At the other end of the scale are information campaigns that aim to achieve political goals on a voluntary basis by providing information to the relevant stakeholders and improving their awareness. A third group of steering instruments rely on incentives. Targeted behavioural changes should be brought about by rewarding the desired behaviour or punishing unwanted behaviour. Subsidies are a typical example of reward-based incentives, while an environmental tax is an example of a punishment-based incentive.

Effective political steering is generally achieved with a combination of instruments. The project «Acceptance of renewable energy» has identified conditions at the various levels of the federal system that prove beneficial for the promotion of renewable energy. The compensatory feed-in remuneration (KEV) of the federal government, for example, influences the profitability of projects for renewable energy.[87] At the same time, it increases the scope both for the qualitative optimisation of a project and the identification of compromise solutions. There is also the question of how the federal government can support the achievement of energy-efficiency objectives without having a negative impact on the freedom of the cantons. Energy research, an area for which the federal government is primarily responsible, plays a key role in this regard. However, a further important factor is the communication that the federal government promotes, for example, via the «Swiss Energy» programme.

Federal government – steering more efficient than promotion

The federal level is responsible for the political framework conditions that advance the implementation of Energy Strategy 2050. It primarily concerns market organisation, energy prices, the subsidisation of eligible energy sources and the support of energy-efficiency measures (federal building stock improvement programme, competitive tenders, etc.). The framework conditions should be structured in a way that automatically causes people to behave in the desired manner.

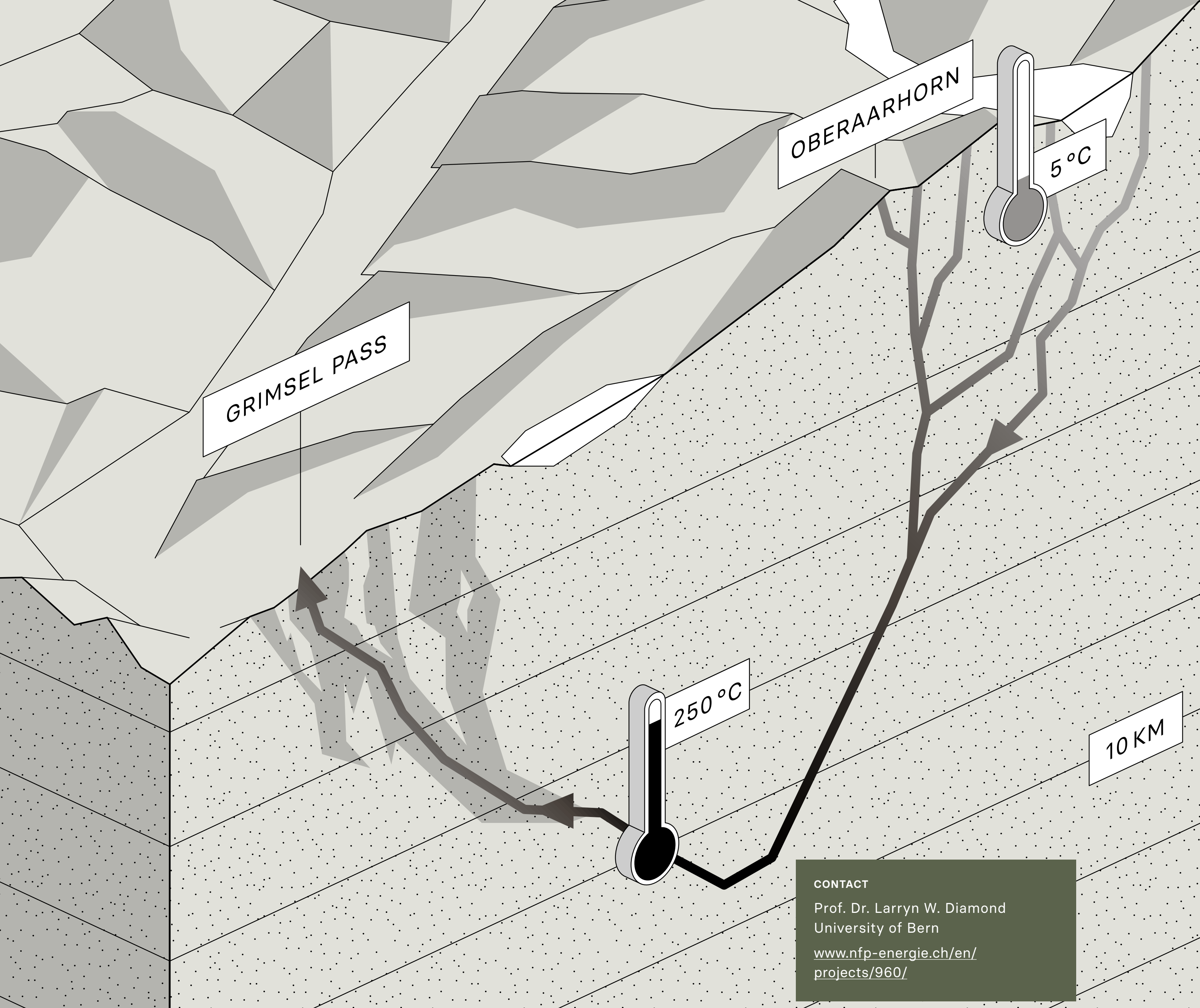
With compensatory feed-in remuneration (KEV), the federal government possesses a steering instrument that makes a substantial contribution to the promotion of renewable energy in Switzerland. The financial means to this end are limited, however, and the instrument will expire at the end of 2022. Scientists have repeatedly concluded that in the area of climate and energy policy environmental goals can be achieved most efficiently with incentive systems. Ideally, incentive systems – such as the incentive tax on fossil fuels – are cost-neutral for the state treasury. Incentive taxes also prove to be both significantly more cost-effective than promotion measures such as subsidies and also more efficient. Their steering effect has an impact everywhere and on every energy-relevant decision taken by households and companies. This means the effects are spread more widely. With a steering measure, for example, a third of all households are better off, while with a promotion strategy almost all households ultimately lose out. This is because although they provide the financing of a promotion measure, they do not benefit from it.[88/89]

Politically, incentive-based steering instruments have proven especially unpopular, however. Political players and the general population often prefer rules and bans. Among other reasons, this is because the costs of an incentive-based measure, for example a tax, are more directly visible than they are upon the adoption of a ban or rule. In practice, information campaigns are used even more frequently. As the softest form of steering, they often represent the lowest common denominator among political players with different preferences and ideas. While they are a necessary requirement, they suffer from the disadvantage of limited effectiveness.

87 [Acceptance of renewable energy]

88 [Promotion or steering-based energy policy]

89 Synthesis on the main topic of «Market Conditions and Regulation» of the NRP «Energy». SNSF



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PROJECT #geoenergy #geology #risk

«Deep underground heat reservoirs»

If geothermal energy is to be used for electricity production, it requires temperatures of over 150°C to drive a power plant turbine with steam. These can be found at a depth of four to six kilometres. Either hot water can be pumped directly from this depth (hydrothermal) or cold water is fed underground where it heats up and is then pumped upwards via a second borehole (petrothermal). As the research team showed, the potential for hydrothermal electricity generation in Switzerland is limited for geological reasons. However, near the Grimsel Pass, the team has identified a fault zone in which surface water from the Oberaarhorn area heats up to between 230°C and 250°C at a depth of around 10 kilometres and finally returns to the surface near the Grimsel Pass. The geological and geophysical investigations suggest that **tectonic fault zones, such as those found in the central Alps and the area around the Rhone Valley, can be promising sources for electricity or heat generation.**

Versatile role of cantons

A key role in the implementation of energy-policy objectives is assigned to the cantons. They each develop specific instruments with which they supplement compensatory feed-in remuneration (KEV) in promoting renewable energy. The cantons use their room for manoeuvre in order to shape cantonal energy policy in accordance with their priorities and viewpoints – with the consequence that the 26 Swiss cantons act differently in regulating and promoting the expansion of renewable energy (Sager 2014).

In particular, the cantons are called on to take action in connection with energy measures in the building sector, the distribution of plants for the supplying of renewable energy and the provision of information and advice. In the building industry, they are faced with the challenge of implementing the current model provisions of the cantons in the energy sector (MuKEn).[90]

The approval processes as well as the widely varying cantonal subsidy options for the realisation of plants that provide renewable energy are decisive for how successfully Energy Strategy 2050 can be implemented at a cantonal level. While the cantons share the general focus of Energy Strategy 2050, they set different priorities with respect to energy sources and steering instruments. These different priorities are based on their experiences, the geographic conditions and political preferences. Against this background, it is appropriate if the objectives set by the federal government leave the cantons with room for manoeuvre in order to enable them to develop individual and thus locally accepted solutions.

The cantons also approach the provision of information and advice very differently. The information requirements of the population as well as specific target groups such as tenants, homeowners, building proprietors and business managers are large. The projects of the NRP «Energy» reveal the following: it is important that the population know and understand the challenges relating to energy policy and handle them accordingly. Campaigns that incorporate the social environment of the individuals they address or that are based on the direct participation of people or personal experiences generate much better results than the pure provision of information.[91/92/93]

90 [Regulations for the building stock]

Municipalities – between planning, approval and promotion

Alongside information-based, and to some extent financial and political, opportunities to influence developments, municipalities can also make use of regulative instruments. In particular, in keeping with cantonal structure plans, municipalities can anchor energy supply specifications in communal construction and zone planning. They often separate special zones in which, for example, wind plants are permitted or define areas in which such infrastructure is prohibited. Regulations of this kind are intended to govern in advance interactions between, and the conflicting aims of, different political interests– for example the conflicts that exist between the promotion of infrastructure for renewable energy and the protection of landscapes and animals. For developers who want to invest in the construction of corresponding infrastructure, these local planning instruments represent important framework conditions. In accordance with Switzerland's federal structure, however, they can differ significantly from location to location. In order to reduce the planning uncertainty in the area of wind energy, the federal council adopted the «wind energy concept» in 2017 (ARE 2017). It should bring about the coherent application of existing regulations without pre-empting the final decisions at a communal level.

The difficulties that Switzerland's federal structure entails are just one side of the coin. Federalism also offers opportunities in the sense of a «federal laboratory» – and these need to be utilised (Balthasar et al. 2020). Here, the municipalities play an especially important role – as building proprietors, as plant owners, as political players and as

91 [Sharing economy: hype or promise?]

92 [Understanding household energy consumption]

93 [Promoting energy-sufficient behaviour in cities] supporters of initiatives of local associations and organisations. They have great potential for advancing the realisation of Energy Strategy 2050.

Municipalities often have considerable stakes in energy supply companies and thus in the expansion of production capacity for renewable energy sources. In this context, an important finding is that Swiss citizens better accept renewable energy if it is produced in Switzerland or if it is generated by a Swiss company should it be sourced from abroad. The repeated rejection of the privatisation of electricity production in communal and cantonal votes suggests that state ownership of energy provision also has a positive impact on acceptance.

The strong link between energy provision and the municipalities also entails problems. In light of the increasing complexity of energy solutions, many municipalities do not possess the required personnel and specialist resources to meet the challenges ahead. Certain municipalities also already feel overtaxed by the ever more demanding approval process.

Necessity of horizontal and vertical coordination

Given the large number of areas involved, the transformation of the energy system requires the authorities to ensure greater horizontal coordination between the individual policy areas at all levels, especially for the launch of innovative projects. A typical example here is urban freight logistics.[94] The intelligent regulation of urban freight logistics has effects on policy in the areas of «energy» (fuel consumption), «climate» (CO_2emissions), «transport» (rail and road), «spatial planning» (development areas for work with a focus on logistics) and «finance» (mobility pricing with time- and utilisation-dependent usage fees).

Within the federal system, vertical coordination between the federal government, cantons and municipalities as well as at an international level is just as important. With regard to the promotion of renewable energy, the coordinated planning of priority development areas seems necessary. For example, a cantonal policy that restricts the licensing of small hydropower plants can severely restrict the exploitation of natural and technical potential.[95] Similarly, financial support from the federal government – such as compensatory feed-in remuneration – alone is not enough to overcome local resistance to the exploration of deep geothermal energy[96] At present, there is no comprehensive coordination for the transformation of the energy system as is the case in some areas with the «wind energy» concept or the «transmission lines» sectoral plan (DETEC 2001) of the federal government. With the need to coordinate the manifold requirements and demands, it is advisable to manage the transformation of the energy system on a tripartite basis – i.e. in cooperation with cantons and municipalities – as part of a comprehensive federal government concept.

Finally, coordination challenges also extend to a European level when it comes to the regulation of the liberalisation of the electricity market, its impact on prices and the public promotion of hydropower in the Alpine cantons.[97/98]

94 [Smart urban freight logistics]

95 [Acceptance of renewable energy]

96 [Deep-heat mining]

97 [The future of Swiss hydropower]

98 [Europeanisation of the Swiss energy system]

Remaining dependency on the European energy market

In light of the importance of the energy supply for the economy as a whole, great significance is also assigned to the objective of supply security. Due to the international and global networking of the energy systems as well as the intricacy of the operation of the transmission grid, the question of the security of a country's energy supply is extremely complex. The Federal Electricity Commission (ElCom) concludes that Switzerland's supply security is assured up to 2025 provided that the load and supply portfolio develops in line with the federal government's Energy Perspectives 2050 (SFOE 2013) (ElCom 2018). However, it remains substantially dependent on developments abroad and integration within the European energy market (see section 3.8).[99]

The situation becomes critical, for example, as soon as Germany not only phases out its nuclear energy facilities, but also its coal-based electricity production – which is planned by 2038. A greater decoupling of Switzerland from the EU electricity market could also cause instabilities in the supply grids. In order to increase supply security, a possible expansion of reservoirs, contractually secured strategic reserves, certificate-based performance obligations and a diversified plant network are all potential options. In particular, in order to make long-term investments in the Swiss plant network attractive, corresponding regulatory framework conditions and new investment strategies are required as shown by the project «Investments in hydropower» (see page 56).[100] In order to guarantee the stability of the grid, it is also necessary to expand the pipeline network as planned.

99 [Europeanisation of the Swiss energy system]
100 [Investments in hydropower]

3.8 The European context

Scenarios in the Switzerland-EU relationship

The historically prominent role of Switzerland in the European electricity sector has declined due to the advancing integration of European energy markets and the country's strained relations with the EU. To what extent Switzerland will in future still be able to exert an influence informally due to the physical dependencies of international electricity grids, its position as a transit country to Italy and its technical expertise is difficult to foresee. Based on the current status of the negotiations, there are three scenarios:[101]

● **Scenario 1 – The institutional framework agreement is signed in its current form or in a renegotiated form.**

The negotiations on the electricity agreement can then be continued. The most controversial issues are state aid regulations and supervision («governance of supply companies»), full market liberalisation, subsidies for electricity production from hydropower and the further unbundling of the distribution grids. Should an agreement be reached, Switzerland can participate in the European processes and markets within a few years. Transitional solutions would be agreed for the interim period.

● **Scenario 2 – The institutional framework agreement is not signed.**

The conclusion of an electricity agreement is made impossible for the foreseeable future with a negative impact on the room for manoeuvre of the Swiss electricity sector, the efficient safeguarding of supply security and the wholesale prices on the electricity market. Even in this scenario, there remains potential scope for selected agreements, such as the agreement regarding unplanned grid flows reached by the

101 [Integration of the Swiss energy system in European energy policy]

Federal Electricity Commission (ElCom). Equal market access for Swiss electricity companies would, however, remain in the balance for longer irrespective of whether Swiss legislation would continue to be designed in a way that is compatible with European law.

● **Scenario 3 – The institutional framework agreement is also not signed. Moreover, no provisional agreement can be reached on equal access to the internal electricity market.**

Even if the physical cross-border exchange of electricity continues: permanent exclusion from European trading platforms will lead to significantly higher system costs and thus to welfare losses. Since Switzerland's ability to import electricity is likely to decline, high investments will be necessary in domestic equalisation reserves and in the storage of seasonal water and solar electricity.

According to simulations of the project «Europeanisation of the Swiss energy system», Swiss consumers will have to accept disadvantages should an electricity agreement fail to be reached: the wholesale price for electricity in Switzerland will therefore be significantly higher than in other European countries and will thus impair the competitiveness of energy-intensive industries. Switzerland's annual trade deficit in electricity trading with neighbouring countries and the risk of supply bottlenecks are likely to increase.

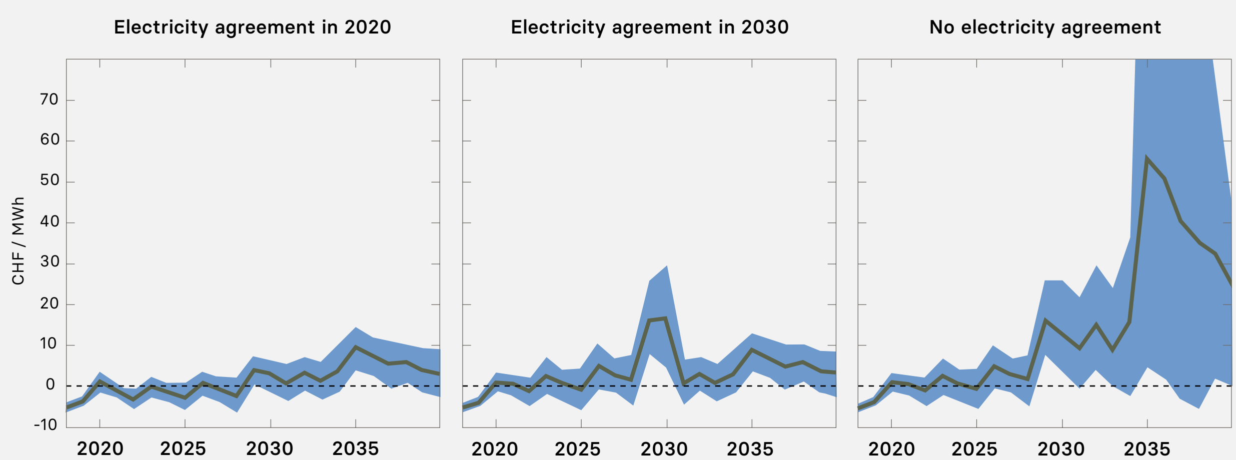

Figure 11

Difference between Swiss wholesale prices and the EU average. The line represents the annual average, the shaded area the 90% confidence interval.[100]

Increasing deterioration of cross-border trade

Due to the fact that Switzerland has only in part replicated the liberalisation of the markets and the harmonisation of market regulations by the EU, trading conditions for Switzerland's major electricity companies, in particular, have deteriorated. According to the project «Europeanisation of the Swiss energy system», almost all stakeholders in the Swiss energy sector regard liberalisation as important. An efficient link to the European electricity trading markets is also given high priority in surveys.[102]

For the cross-border exchange of electricity between Switzerland and the EU, the line capacity at the border must today be explicitly acquired – in contrast to the transfer capacities at the borders of most European countries. The lack of commercial market coupling leads to uncertainties and risks for trading companies, meaning that less electricity is traded across borders. This can lead to welfare losses and excessive wholesale prices on both sides of the border.

A new method for calculating cross-border transmission capacity («flow-based») introduced in 2014 has reduced Switzerland's ability to import electricity. In the absence of an electricity agreement with equivalent trading conditions for Swiss market players, cross-border trade is likely to continue to decline. Over the next few years, all EU member states will grow together into a single coupled electricity market, from which Switzerland will be partially excluded. Since hydropower, which is most affected by this, plays an important role in the targeted energy system (Energy Strategy 2050), the corresponding legal framework conditions in Switzerland must be reviewed and, if necessary, adapted. Without an electricity agreement, the technical elements of European law should nevertheless be adopted, while for market access the provisional retention of differentiated regulations is possible and presumably also sensible.

Room for manoeuvre for future promotion

At present, certain support measures for large Swiss hydropower plants, in particular, conflict with European state aid law. The EU Commission wishes to expose such major facilities increasingly to market price signals and ensure that any promotion measures are competitive in nature. If the promotion instruments are designed to be technology-neutral, this would lead to an increased expansion of those supply forms that are relatively inexpensive and/or easy to implement in Switzerland in terms of spatial planning, such as hydropower and photovoltaic plants. Such specialisation would be less problematic if it was embedded in the European internal electricity market than in a situation without market connections. In the latter case, the legislator would be better advised to align the framework conditions with a well-diversified portfolio of different supply forms.[102]

Market-oriented promotion excluding large domestic plants is currently also possible under European law. By 2030, however, at least 10% of the promotion measures must be opened up to foreign installations. Without an electricity agreement, such a step would not be necessary.

For the promotion of small decentralised producers of renewable electricity, exemptions from competitive procedures are still possible under the new European legislation. Instruments such as investment aid or exemption from grid charges for own consumption can also be used. Most of the promotion measures currently in place in Switzerland in this area, which will, however, expire after 2022, are compatible with European law. The situation of decentralised producers could be further improved in line with European law by enabling them, for example, to sell their electricity products to a wider range of players through peer-to-peer trading or power purchase agreements (PPAs).

102 [Europeanisation of the Swiss energy system]

The total of more than 100 research projects of the NRP «Energy» have generated a wealth of individual results. Some of these projects have created technological innovations, while others have analysed the economic or social environment. The syntheses available on the web portal www.nrp-energy.ch have brought together thematically related projects and resulted in new, comprehensive findings. Those aspects that appear to be especially relevant for the transformation from the perspective of the NRP «Energy» are highlighted below. It can be seen that the socio-political aspects are just as important for the transformation as the technical ones; they represent the key to implementing technical solutions.

4

Conclusion

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Numerous technical solutions are available that can contribute significantly to the transformation of the energy system. Each and every individual is called on to seize the opportunities for the transformation of the energy system. This also includes regulation that provides motivation and steers people in the desired direction. This has not yet been achieved to the necessary extent.

Magazine «E&» | Energy & Lifestyle, Illustration: Diana Pfammatter

4.1 Untapped potential in the building stock

The operation of buildings accounts for around two-fifths of final energy requirements. Increasing the energy efficiency of the building stock, its energy renovation, is a cornerstone of Energy Strategy 2050. With their roof and facade surfaces, buildings offer a wide range of options for photovoltaics that have not been sufficiently utilised to date.

The energy renovation of the building stock is taking place much too slowly and must be intensified.

At the current renovation rate of only around 1.5% per year for residential and office buildings, the renovation of old buildings will take until the end of this century – far too long to make the expected contribution to the transformation of the energy system. This process must be accelerated. The promotion measures taken so far are proving to be inadequate.

Building facades offer great potential for photovoltaics.

One of the key technologies for the provision of renewable energy is Photovoltaics. Its output should be increased well over tenfold from today until 2050. In order to achieve this goal, it is necessary for further space to be made available. While PV parks in open spaces enjoy almost zero acceptance in Switzerland, existing (tourism) infrastructure facilities and, above all, building facades offer available potential. However, building-integrated photovoltaics still have a niche existence today. This is due to a lack of knowledge among building owners and architects, a lack of social and political pressure and, at present, still somewhat uncertain costs. With regard to design requirements, the range of PV panels for building-integrated applications already meets high demands today. However, the diversity of offerings is still growing, also thanks to the work of the NRP «Energy».

4.2 Hydropower between investment needs and sustainability

Hydropower remains an essential element of the future Swiss energy system. It makes a significant contribution to the energy supply, contributes to supply security and offsets fluctuations in the provision of electricity. Hydropower also enjoys broad acceptance. There are opportunities to optimise its use. However, its expansion is greatly limited by economic and environmental framework conditions.

Hydropower requires more attention.

The existing hydropower infrastructure requires considerable maintenance. Due to various uncertainties, however, the necessary investments are not made by the power plant owners. The precarious earnings situation in the short to medium term collides with the long-term nature of the necessary investment of several decades. The applicable concession regulations with the foreseeable threat of a reversion of the power plants from their owners to the grantors of concessions also hamper investment.

Hydropower plants require a holistic assessment.

The use of hydropower finds itself in a fundamental conflict with the ecology of natural waters. Numerous hydropower plants still have a need for residual flow remediation. At the same time, the current residual flow regulations are insufficiently implemented in order to achieve the desired biodiversity goals. Retreating glaciers are opening up potential for new reservoirs. However, their use requires a comprehensive sustainability assessment. In future it will not only be necessary to assess individual plants, but also to exploit the potential offered throughout Switzerland, as part of an overall assessment, to determine where the relationship between energy use and environmental damage is most favourable. This calls for greater coordination and the consideration of all hydropower plants in equal measure.

4.3 Population motivation

The transformation of the energy system is to a large extent a task for society. Each and every one of us is challenged in different roles to make a contribution to this process. The population is willing to take action if the specific possibilities are known and can be used. In some respects, however, there are considerable gaps in information and knowledge.

Social norms determine behaviour.

Economic considerations only play a secondary role in the decisions taken by people when completing their daily shopping, making purchases and executing investments. The first step is a (product) choice that is strongly influenced by social norms. It is therefore often decisive whether something is socially accepted or even in vogue. Only then does the question of cost arise. For example, if e-bikes are considered «cool», the willingness to buy this type of bike grows, even if the costs are high. This social assessment and classification plays an important role in the transformation of the energy system. And it can be utilised to advance the transformation process. Turning meaningful energy-efficient behavioural patterns into a trend therefore represents a promising and often underused strategy.

A broadly financed energy supply enjoys high credibility.

Consumers have a considerable interest in co-financing renewable energy for self-sufficiency. Protected by compensatory feed-in remuneration (KEV) and supported by local and regional energy suppliers, companies or organisations such as energy cooperatives bundle this fragmented financing. A high degree of identification with the structures close to the user proves to be a key factor. This results in a high level of acceptance for local and regional energy measures and investment in renewable energy infrastructure. From this perspective, the approximately 700 existing local and regional energy suppliers represent an important basis for the further transformation of the energy system. They enjoy a high degree of support and credibility for innovative measures and infrastructure investment, even if they are made abroad.

4.4 Need for re-regulation and enhanced implementation

Energy-relevant legislation, which covers much more than energy legislation in the narrower sense, is still insufficiently geared towards the energy system of the future. In some areas, therefore, this slows down the implementation of promising technical solutions. The lack of coordination between the various political and administrative sectors and the state levels in the implementation of legal mandates also decelerates the transformation. Cities and municipalities, in particular, would also have the power to advance the transformation more actively. They have a wide range of information-related, financial and regulatory intervention options at their disposal.

Legislation does not support the transformation of the energy system to the necessary extent.

The current energy regime is characterised by the coexistence of the various energy sources and by an energy distribution logic based on a mono-directional supply chain (supply – distribution – use). The transformation of the energy system fundamentally changes this situation. In order to offset the fluctuations in the provision of renewable energy, it is necessary to overcome the separation of the various energy sources by means of sector coupling – specifically, for example, in decentralised multi-energy hub systems (DMES). The increasing importance of prosumers – stakeholders who not only use energy, but also provide it on a decentralised basis – is completely changing the current distribution logic. The present energy legislation, which has a strong sectoral orientation, does not do justice to these new dynamics. It makes it more difficult or even impossible to use various available technologies and to link technologies and energy sources. In many areas, it slows down the good will that exists here to drive forward the transformation of the energy system. The past shows that every energy regime needs its own specific regulatory framework conditions. Ongoing revision work on energy legislation is capable of bringing about some of the necessary adjustments. But only careful re-regulation that goes beyond the energy legislation will create the necessary room for manoeuvre in which technological potential can be realised.

The energy system of the future requires more flexibility.

The higher share of solar and wind energy in the energy system of the future will lead to more marked fluctuations in the energy supply. An agile load management system should offset these fluctuations – this will entail great technical challenges in the control system. In addition, more flexibility must be created in the energy system – in terms of space, time and the energy mix.
With respect to space, the necessary flexibility can be ensured via efficient distribution grids.
The planned expansion of the Swiss electricity distribution grid is therefore necessary and must be implemented accordingly. There is no need for expansion that goes beyond this. Temporal flexibility is created by storage solutions of various types – reservoirs, batteries, compressed air reservoirs, etc. The linking of the various energy sources enables flexibility with regard to the energy mix, for example with the production of hydrogen or synthesised methane using electricity from solar or wind power plants. The greater flexibility of the energy system not only requires technical solutions, but also regulatory ones. The structure of grid charges represents partly insurmountable economic obstacles for sector coupling. Regulatory adjustments can create the necessary room for manoeuvre.

The transformation of the energy system requires greater coordination among state actors.

In Switzerland's federal system, all levels of government deal with energy-policy tasks relating to Energy Strategy 2050. These relate to different implementation areas at the individual levels. However, energy policy activities are not sufficiently coordinated either horizontally or vertically. The increased coordination of these activities and implementation practices has considerable potential to make the transformation of the energy system more effective and thus faster.

Cities and municipalities have considerable room for manoeuvre for an active energy policy.

Cities and municipalities as well as municipal associations and regions have a great deal of room for manoeuvre to help shape and advance the transformation of the energy system – in terms of planning, organisation and communication. The scope of the municipalities goes far beyond the implementation of the energy legislation. Within the framework of usage planning, they define the planning framework, which, for example, makes possible the realisation of building-integrated photovoltaics, decentralised multi-energy hub systems (DMES) or wind turbines. As (co-)owners of local energy supply companies, they can support the introduction of «smart meters» or help to increase production capacity for renewable energy sources. In doing so, they can rely on a high level of acceptance for state ownership of the energy supply. Cities and municipalities also play a key role in the transport sector and have many competences. For example, they can help to make the distribution of goods more environmentally friendly or convert public buses to renewable energy. Thanks to their proximity to the population, cities and municipalities are predestined to make innovations in the energy sector accessible to them or to motivate the population with information and educational activities to participate in the transformation. They can also support initiatives of local associations and organisations that promote energy-saving behaviour through innovative practices. The «Energy City» and «Energy Region» programmes supported by the federal government enable an exchange of experiences and provide management instruments for the planning, implementation and measurement of a successful communal or regional energy policy.

Research can very well provide answers to individual questions and develop specific solutions. However, this can also result in conflicts of interest between the individual approaches. It is not up to the researchers to carry out the necessary social balancing of interests. Rather, this is a matter for politicians and the electorate.

The recommendations developed below therefore represent an intermediate step on the way from research to implementation. They are essentially based on the results of the individual research projects and the thematic syntheses. As part of workshops, they were discussed and evaluated with various stakeholder groups and reconciled in line with their experience.

5

Recommendations

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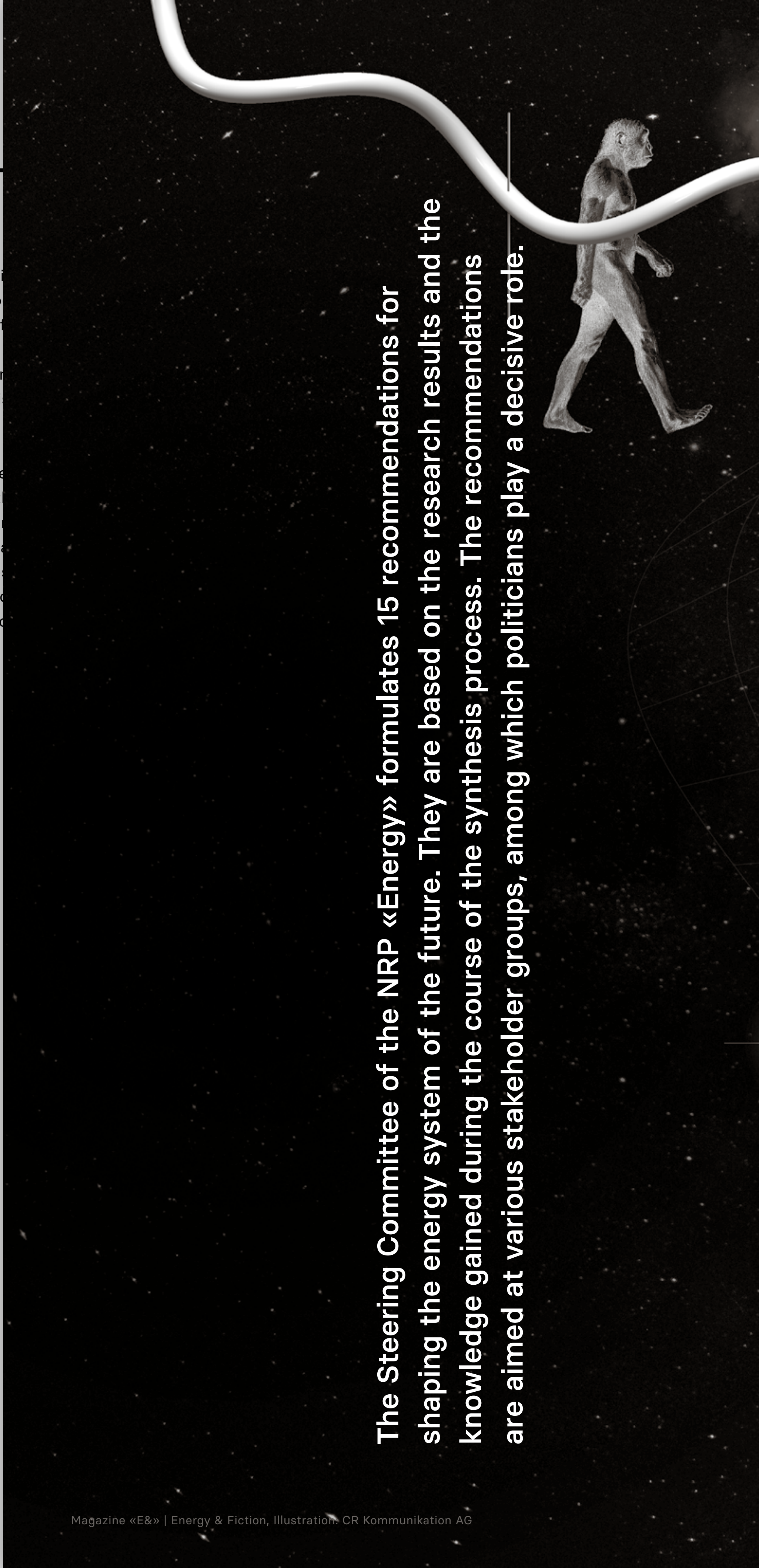

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TODAY
TODAY

Stakeholder: politicians

Develop a federal concept for the transformation of the energy system!

Poorly coordinated or even uncoordinated planning and approval processes put the brakes on many energy infrastructure projects. The federal government, cantons and municipalities should therefore create a reliable basis in the form of a jointly developed concept in order to reconcile the interests of the various governmental levels and break down barriers.

The planning and the realisation of energy infrastructure generally require complex procedures involving federal, cantonal and municipal authorities and involve a wide range of stakeholders, including, in particular, organisations entitled to lodge complaints. The sectoral plans and concepts adopted so far concern only certain types of infrastructure such as high-voltage power lines and wind turbines. Energy legislation is also subdivided into numerous special decrees that focus on individual energy sources and impede the necessary overall view of the energy system. At the same time, a wide range of protection interests need to be taken into account. With a concept jointly developed by the federal government, cantons and municipalities, the federal government can show how spatially effective and energy-policy tasks, which are connected to the transformation of the energy system, are coordinated, and how it supports the corresponding efforts of the authorities at all levels. The focus here is placed on coordination in terms of content and procedure with the aim of accelerating the implementation of infrastructure projects that are necessary for Energy Strategy 2050.

Quickly clarify the relationship between Switzerland and the EU in the interest of assuring supply security in the electricity sector!

Switzerland uses electricity imports to offset the marked seasonal fluctuations in electricity production from hydropower plants. Relations with the EU and thus the European energy markets will in future determine how and at what cost this compensation can be assured. In the absence of an electricity agreement, the associated costs will be much higher.

The historically prominent role of Switzerland in the European electricity sector has declined due to the advancing integration of European energy markets and the country's strained relations with the EU. Studies suggest that supply security can be assured up to 2025 irrespective of how Switzerland's relations with the EU are governed. However, the situation may become critical, for example, as soon as Germany not only phases out its nuclear energy facilities, but also its coal-based electricity production – which is planned by 2038. A greater decoupling of Switzerland from the EU electricity market could cause instability in the supply grids. The measures that are necessary to ensure supply security in this case are associated with higher costs and require a regulatory framework. To prepare accordingly, Switzerland should quickly clarify its relations with the EU.

Promote energy efficiency with targeted regulations and push ahead with the expansion of renewable energy!

Many of the technologies that are required for the transformation of the energy system are already available. However, in the area of buildings and in the mobility sector, in particular, their use on a voluntary basis alone is insufficient. In order to achieve the set objectives, regulatory interventions

are therefore required alongside market-economic incentives. Various preliminary policy decisions that have been taken recently are along the right lines.

Due to the traffic-inducing effect of new mobility services and the diverse rebound effects associated with them alone, the transformation of the energy system will not be achievable with purely technology-oriented and/or exclusively market-driven strategies. The situation is similar for the building sector: the energy renovation rate falls far short of allowing the objectives of Energy Strategy 2050 to be achieved. Sustainable mobility behaviour requires both «push and pull» measures. In its role as financial backer and operator of the infrastructure as well as a co-procurer of services, the state will play a key formative role in the area of mobility. Accordingly, it is important that it actively accompanies the new developments and steers them towards the politically set goals, for example by facilitating access for particularly energy-efficient suppliers in inner cities, by adopting more effective regulations on fuel-consumption for vehicles or by promoting mobility apps that prominently highlight the most energy-efficient options. Organisational measures such as carsharing and carpooling can also have a clear impact in the desired direction.

In the case of heat generation in the building sector, the changeover to non-fossil energy sources can be accelerated with steering measures such as a CO_2 tax. In contrast, to achieve the desired increases in efficiency in the area of the building shell, especially for old buildings, additional regulations and incentives are required in order to increase the share of renewable energy utilisation. Promotion measures such as the federal building stock improvement programme are also still needed.

Support the expansion of renewable energy with a comprehensive and effective CO_2 incentive tax!

Steering measures are more effective and cost-efficient than promotion. A CO_2 incentive tax on fossil energy sources is therefore especially suitable for advancing the transformation of the energy system.

The market alone is not in a position to trigger the investments required for the expansion of renewable energy; and voluntary action will not suffice to bring about the changes in behaviour necessary, among the population or economic players, for the transformation of the energy system. However, incentive taxes prove to be an effective instrument for encouraging desired behaviour. They are up to five times more cost effective than promotion measures such as subsidies and have an impact on all relevant decisions. The effects are therefore very broad. This approach allows a large share of households to benefit. In the case of a promotion strategy, on the other hand, everybody pays but only few benefit. Incentive taxes have proved successful in various areas, for example the CO_2 tax on fuels and the tax on volatile organic compounds (VOC tax), and are generally accepted. If the existing mechanisms for energy-intensive companies are maintained, incentive taxes on CO_2 emissions have no negative impact on economic development and should therefore be applied in all energy sectors to the greatest possible extent. The acceptance of incentive taxes can be increased by means of transparent reimbursement structures and the provision of in-depth information on how they work. A defined progressive development improves predictability for companies.

Focus hydropower on its stabilising function within the energy system!

New renewable energy is faced with the problem that production and use often do not coincide. Hydropower fulfils a key role in this context: it stabilises the supply system and ensures the technical supply security of the Swiss energy system. This function can also serve as a basis for financial compensation.

As large storage solutions, reservoirs play a key role in the regulation of the Swiss energy system. They serve to regulate capacity and perform stabilising functions. Regulatory framework conditions need to be created to strengthen this function and make investments in hydropower plants an attractive proposition. In order to perform this stabilising role in the transformed energy system, additional storage capacity is required.

Base water fees on earnings!

In 2024, a new solution will need to be approved for the water fee. It should be based on income and thus reflect the market price and production costs. The new solution must also take account of the interests of mountain areas. For these areas, water fees are far more important from an economic perspective than they are for electricity producers.

Water fees are a remuneration paid by electricity producers to the mountain cantons and municipalities for the use of their water resources. In 2015, they totalled around CHF 560 million. In numerous municipalities, water fees account for a significant share (20% to 50 %) of financial resources. Flexible and earnings-based water fees are now deemed to be more in line with the market than fixed maximum values that are solely dependent on installed capacity and not on the electricity actually produced. However, flexible water fees increase the risk faced by the resource owners, that is the mountain municipalities and cantons, while the risk faced by the power plant operators is reduced. For the latter, the level of the water fee is, in most cases, of only minor significance for revenues. Flexible, earnings-based water fees should therefore be introduced that are structured according to the principles of revenue sharing between the resource owners, i.e. the municipalities and cantons, and the power plant operators. To ensure an overall view is adopted, the new regulations should also take account of regional policy and regional economic factors.

Create optimal conditions for financing models in which the population can participate!

Financial involvement in infrastructure investment for renewable energy creates identification. Locally based organisations such as associations, cooperatives and neighbourhood organisations create acceptance and help to advance the expansion of renewable energy.

The chances that new energy infrastructure will be accepted increases if participation in the benefits from renewable energy is emphasised and promoted more strongly. Here, the most attractive models appear to be those that make municipalities or private individuals co-owners and thus generate economic benefits for them, for example as part of local public limited companies, associations, cooperatives or neighbourhood organisations. Municipalities can publicly promote such models by contributing to the financing of the relevant infrastructure – for example with loans – or making public spaces available for this purpose, such as roofs for solar panels. Pension funds should also be provided with the opportunity to contribute to the financing of energy infrastructure. Local power plants can make their know-how available, guarantee grid access for the electricity generated from renewable energy sources or feed this electricity into the grid at an attractive tariff.

Motivate cities and municipalities to utilise their room for manoeuvre in the energy sector more actively!

Cities and municipalities have a wide range of possibilities for helping to shape the transformation of the energy system in their role as building owners as well as proprietors and operators of public plants and businesses and in their function as political players and supporters of local initiatives. They can become active – not only in the energy sector – in planning, organisation and communication.

Despite numerous opportunities, cities and municipalities often find it difficult to pursue an active energy policy. In addition to political will, such a policy necessitates a certain level of creativity and an interdisciplinary approach. It is not only in the areas of energy production, energy distribution and in their role as building owners that municipalities have considerable room for manoeuvre in transforming the energy system. The «Energy City» and «Energy Region» programmes supported by the federal government make possible an exchange of experience and provide management instruments for the planning, implementation and measurement of a successful communal or regional energy policy.

Stakeholder: politicians / businesses

Realise CO_2-free urban logistics by 2050!

If urban agglomerations are supplied in a CO_2-free manner, 7% of the corresponding efficiency objectives of Energy Strategy 2050 and around 9% of the targeted reduction in greenhouse gas emissions could be achieved. Cantons, cities and municipalities should therefore create corresponding framework conditions and work together with logistics stakeholders.

The logistics market is growing almost unchecked – expanding by nearly a quarter within ten years. Trends such as e-commerce, reduced warehousing, the decline in delivery units and increasing delivery frequencies are the defining drivers. A large share of logistics is based on fossil energy. The objective of achieving CO_2-free urban freight logistics is economically feasible and is accepted by the logistics firms. Realising this goal will not only meet energy-relative targets. It will also generate additional benefits that are broadly accepted by society by reducing emissions of air pollutants and noise in urban areas and thus generally increasing the quality of life. The goal of bringing about CO_2-free urban freight logistics requires measures such as CO_2-free vehicle drives, mobility pricing, road use conditions, energy-efficiency labels, cooperation and the planning of logistics centres. It is essential that everyone involved must be active in this respect and must work in close cooperation. By means of holistic planning, public authorities should create suitable framework conditions in urban areas, while logistics and transport service providers should, among other things, align their supply chains with these conditions, determine suitable locations for their logistics centres and purchase vehicles with CO_2-free drives.

Stakeholder: politicians / energy suppliers

Realise decentralised multi-energy hub systems (DMES)!

DMES make possible the highly efficient use of energy provided on a decentralised basis. For these to be realised, energy provision and supply must be viewed as a whole at both a local and regional level. Self-organisation and state regulation should complement each other in the best way possible. The municipalities as well as the federal government and the cantons need to perform the preliminary planning and legal work.

Decentralised multi-energy hub systems (DMES) link electricity, gas and heating grids as well as storage options and energy consumers in an intelligent manner. Energy produced in a decentralised manner can in turn be used efficiently on a decentralised basis – locally or regionally or within a specific district, village or neighbourhood. It can also be expected that such energy will enjoy a high level of acceptance thanks to the local context.
In this way, the variable availability of renewable energy can be buffered. The supply monopolies of local and regional energy suppliers are an obstacle to the realisation of DMES. The implementation of DMES also requires the entire energy system to be taken into account in both a local and regional context. This means moving away from viewing the individual energy sources in isolation as well as from the individual energy supply of specific buildings and businesses. What is needed is municipalities, together with their power plants, that are able to identify the potential for DMES and, through providing energy structure plans and active support, can accelerate the realisation of DMES. For their part, the federal government and the cantons should ensure that the necessary legal framework conditions (e.g. connection obligation, data protection, data management) are in place.

Stakeholder: cantonal administrations

Adjust residual flow regimes in line with environmental needs!

At present, the Waters Protection Act is not being adequately implemented with a view to meeting environmental goals. The targeted level of biodiversity in river sections beneath dams is not being achieved. The cantons should therefore implement the legislation in a way that enables residual flow management to accomplish the environmental objectives. Appropriate measures require more water and reduce electricity production.

The current implementation of residual flow provisions does not ensure the ecological conditions that are required for the preservation of biodiversity in the residual flow stretches. With a view to economic interests, it is too often the case that minimum requirements are implemented and exceptions are issued. In rivers with inadequate bedload dynamics, the riverbed becomes compressed and is no longer suitable as a spawning substrate. Natural floods can no longer sufficiently flush out the pore space blocked with fine sediments and the supply of oxygen declines. Constant residual flows cannot restore the diversity of habitats and creatures. A natural situation can be achieved through bigger floods and greater temporal and spatial variability in the water flow. Artificial floods and measures aimed at managing bedload transport are therefore increasingly coming under the spotlight. The renewal of concessions should be used as an opportunity to optimise the ecological conditions. Appropriate measures have consequences for electricity production and because of this also have an influence on the achievement of Energy Strategy 2050.

Stakeholder: energy suppliers

Actively involve the population in the planning of infrastructure projects from the outset!

Active participation strengthens identification and promotes acceptance. Project initiators should therefore make the planning processes for projects in the area of renewable energy participatory from the outset.

Switzerland is very much characterised by a culture of participation and co-determination. This needs to be taken into account during the structuring of political measures and projects relating to renewable energy. Project initiators should involve, in particular, the segment of the population affected, from the outset of the planning stage. Participation is only successful, however, if it is implemented professionally. This means properly considering the concerns of the population. Issues that are raised must be taken seriously by the project initiators and dealt with in a transparent and fair manner. Likewise, interests need to be clarified in good time and the process of weighing these up must be well documented.

Create incentives to save energy with flexible and dynamic electricity tariffs, reward targets and information!

Energy distributors should develop and use flexible and dynamic electricity tariff models that create an incentive to reduce electricity consumption and energy costs. The combination of bonus elements that reward the achievement of saving objectives increases the acceptance enjoyed by such tariff models.

There is broad acceptance for offering renewable energy with a price surcharge as a standard offer, which must be deliberately deselected if consumers wish to access conventional energy at lower prices. As a first step, «green defaults», such as these, can be introduced immediately by energy distributors. However, in order to advance the transformation of the energy system further, additional new tariff forms will be required. The biggest impact comes from tariff systems that impose additional charges on higher levels of consumption. However, such systems enjoy only limited acceptance among the population and businesses. Rewards – for example on successfully meeting energy-saving goals – can contribute to overcoming this hurdle. The energy suppliers are called on to develop corresponding tariff models (bonus-penalty systems) for the various energy sources. It should be possible for energy consumers to select such a tariff model as an alternative to existing tariffs. In this case, target values, as well as the relevant bonuses and penalties, would be agreed on an individual basis between the energy suppliers and energy consumers. The willingness of consumers to accept such variable tariffs is high. These systems already contribute to cushioning peak demands in terms of electricity consumption thus making the energy system more cost-effective. The more the energy system is geared towards renewable energy and the decentralised provision of energy, the more important it is to reconcile energy supply and demand. It must be ensured that price signals also reach the households. This means that the tariff differences need to be high in order to bring about a change in the behaviour of consumers and to encourage them to purchase devices that can automatically process the signals.

Stakeholder: energy suppliers / public administrations

Communicate knowledge – focussed on target-groups and in a neutral way!

Measures aimed at communicating knowledge and information must devise innovatively designed strategies in order to take account, and make use, of the different levels of knowledge and various motivations of different population groups. The public administrations of the federal government, cantons, cities and municipalities as well as associations and businesses must provide information on how technologies and steering mechanisms function. They must also communicate convincingly that a large part of the available energy-efficiency potential can be tapped without sacrifice or loss of comfort: greater energy-efficiency does not mean less comfort.

The citizens of Switzerland act both as stakeholders who make energy-relevant decisions on a daily basis and as voters who play a crucial role in determining energy policy. For them to be in a position to take these decisions, and also to manage energy carefully, they need knowledge about the problems associated with energy consumption. In this regard, there are some considerable gaps in the population's knowledge. To ensure a differentiated debate on energy-relevant plans, it is of crucial importance to provide the population with long-term and neutral information, as well as the specialists and politicians. Information and awareness-raising campaigns must take specific account of where the target groups find themselves along the continuum «knowledge», «will» and «action». Target-group-oriented information brings knowledge to those areas where there is a particular need in a particular situation.

One possible connecting point is in social practices and norms as these play a significant role in determining what individuals want and how they act. Incorporating energy-relevant behavioural changes in the practices of existing communities, such as sports clubs and neighbourhood associations, and linking these to the quality of life («co-benefits») may prove promising. In all social groups, role models play a key role in opinion formation. Positive experiences – where possible in close proximity to people's living environment – increase both the acceptance of technologies and the willingness to change behaviour. Examples here include pilot plants for the development of decentralised multi-energy hub systems (DMES).

Stakeholder: associations

Increase the accountability of associations!

Associations interact closely with their members and possess sector-specific knowledge that can advance the transformation of the energy system. They should also use their important role in the political decision-making process to win over their members and gain their support for jointly developed solutions.

Associations have wide-ranging networks within the economy and society and at the same time enjoy a high level of trust from their members. They have numerous and important opportunities to become involved in participatory processes, consultation proceedings, parliamentary matters and direct-democratic co-determination. In this way, they contribute to the development of solutions that take account of the relevant property and usage rights. For associations, active participation is also tied to the obligation to stand up for the interests of their members with respect to jointly developed solutions. Local associations that are not directly involved in energy matters can also play an important role. They have the potential to raise awareness among their members concerning the energy impact of their everyday practices and to increase the acceptance of beneficial behavioural changes.

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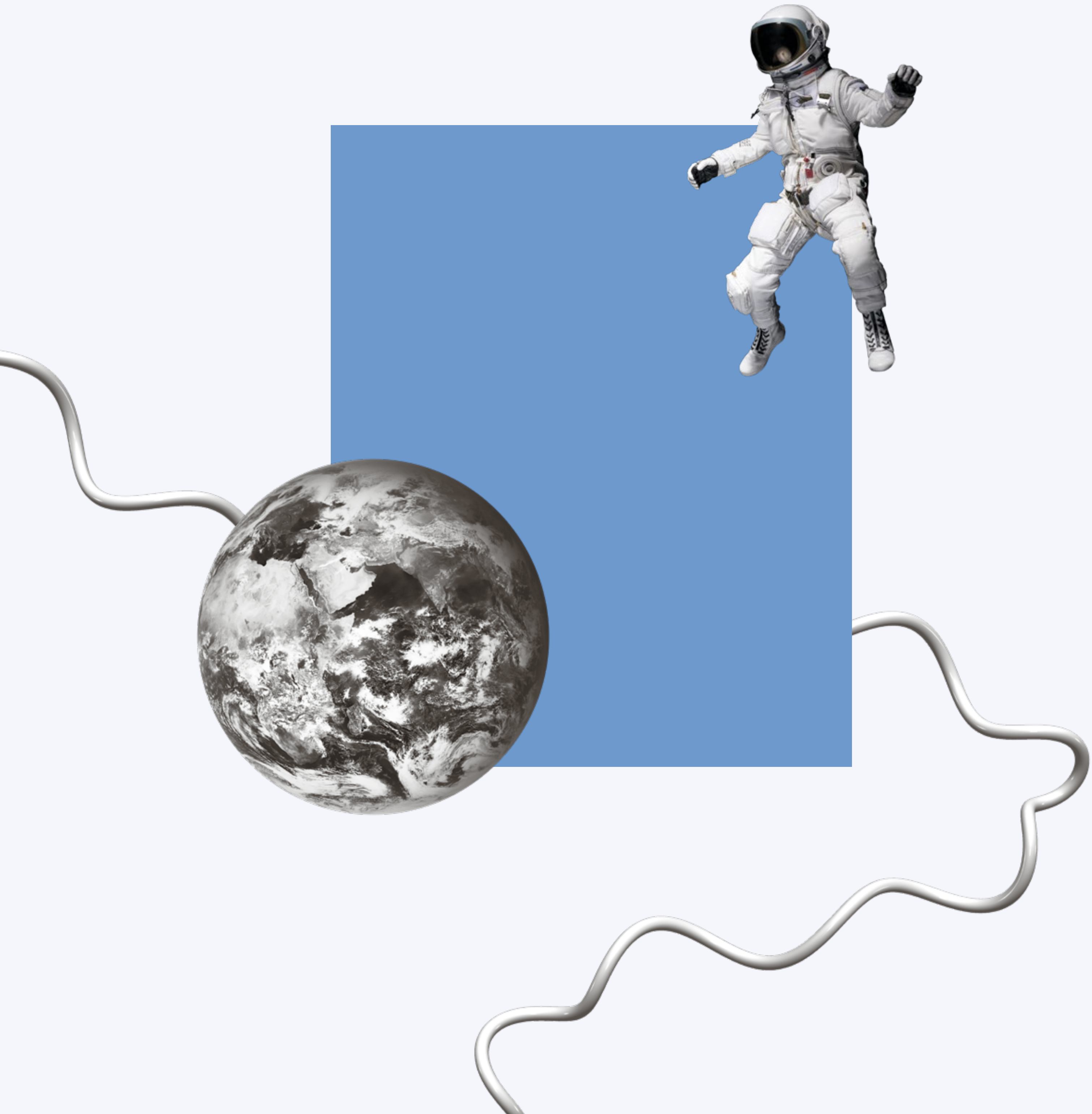

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