Challenges and Opportunities for the Swiss Energy System in Meeting Stringent Climate Mitigation Targets

Evangelos Panos and Ramachandran Kannan

Key messages

- Electrification, efficiency, active participation of consumers in energy supply and demand side management are key pillars for achieving the fast and deep emissions reduction required to go beyond NDC.
- New business models involving microgrids, smart grids, virtual power plants, storage and power-to-gas technologies emerge and create new opportunities for low carbon development.
- The transition to a low carbon energy system requires immediate action, long-term price signals, effective implementation of carbon pricing mechanisms, regulations and legislation for supporting new emerging and exponential technologies.
- The use of the TIMES modelling framework in assessing deep decarbonisation policy scenarios enables an integrated assessment of the challenges, opportunities and trade-offs across the whole energy system in a consistent way that considers complex interdependencies between the energy actors.

E. Panos (✉) · R. Kannan
Laboratory for Energy Systems Analysis, Energy Economics Group,
Paul Scherrer Institut, Villigen, Switzerland
e-mail: evangelos.panos@psi.ch

R. Kannan
e-mail: kannan.ramachandran@psi.ch

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1 Introduction: Zero Emission Challenges in a Nuclear Phase-Out Context

In its Nationally Determined Contribution (NDC) to the Paris Agreement on Climate Change, Switzerland has committed to reducing its greenhouse gas (GHG) emissions by 50% in 2030, compared to 1990 levels. Proportionally, this reduction is to be achieved by 60% domestically and by 40% with the use of international credits (UNFCCC 2015). The Swiss government has formulated an indicative goal to reduce emissions in 2050 by 70–85% compared to 1990, including the use of international credits, as well as the vision to reduce per capita emissions in Switzerland to 1–1.5 t-CO_2eq in long-term (UNFCCC 2015). Given that in Switzerland the CO_2 emissions alone account for about 80% of the total GHG, a CO_2 tax on heating and process fuels was introduced in 2008, which is 96 CHF/t-CO_2 (83 EUR/t-CO_2) in 2018. Around two-thirds of the revenues from the CO_2 levy are redistributed through health insurers and the old-age insurance system; the remaining is used to finance building renovation programmes. From 1990 to 2014, the Kyoto protocol GHG emissions in the country declined by about 10% (BAFU 2016a, b).

The highest-emitting sectors are the transport and buildings, representing almost 2/3 of all emissions. The Swiss electricity sector is already almost CO_2-free as electricity is mainly generated from hydropower (59%), nuclear (33%), and renewables (5%) (BFE 2015). The new Swiss energy strategy aims at gradually phasing out the existing nuclear power (safety is the sole criterion) and promoting energy efficiency and renewable energy (BFE 2017).

Much of the additional sustainable renewable energy potential is on roof-top solar PV (Bauer and Hirschberg 2017). Wind conditions are less beneficial for wind power than in other countries, and wind projects are challenged by social opposition. Expansion of hydropower depends on political and social boundary conditions, though unexploited sustainable potentials are limited. The realisation of additional biomass (mainly manure) faces challenges regarding logistics and costs. Geothermal energy is also a controversial issue in the country, due to induced seismic activity in the recent past (Stauffacher et al. 2015). Finally, carbon capture and storage (CCS) is surrounded by uncertainties in costs and geological storage, additionally to issues related to public perception and the absence of a legal framework (Sutter et al. 2013).

In this context, the phase-out of nuclear energy could risk the ambition of the Swiss climate change mitigation policy and impose challenges for energy stakeholders and policymakers. A decentralised energy system built around small-scale renewable projects would imply that utilities need to move into new service-oriented business models beyond the old commodity-based model of cost-effective supply. Energy consumers would be increasingly interested in managing their energy use patterns and balancing their electricity and heating needs real-time. These developments imply a profound technological shift towards digitalisation, and policymakers have to develop a better understanding of the opportunities, challenges and risks that arise from it.

The limited availability of domestic renewable energy resources, the need for new market designs and legal frameworks, and the social impedance or acceptance of low carbon technologies constitute the climate change mitigation a formidable challenge for Switzerland. This chapter presents a techno-economic feasibility of scaling-up climate change mitigation efforts in a developed country with an innovative economy. It creates a link between national policies and global climate change mitigation efforts, and it assesses national barriers challenges and opportunities that are often overlooked in studies focusing on global deep decarbonisation pathways. The insights provided could be useful to a range of similar developed European countries, regarding resource availability or policies, such as Belgium, Netherlands, Sweden, Germany, Denmark, Austria, Norway, Ireland and the Czech Republic.

Assessment of CO_2 reduction policies for Switzerland, in the context of a nuclear phase-out, has been performed in the past with the modelling frameworks of the International Energy Agency’s—Energy Technology System Analysis Programme (ETSAP), such as the Swiss-MARKAL energy systems model (Kypreos 1999; Schulz et al. 2008; Weidmann et al. 2012), the Swiss-TIMES energy systems model (Kannan and Turton 2016), the CROSS-border Swiss-TIMES electricity model (Pattupara and Kannan 2016); and non-ETSAP tools such as the CITE Computable General Equilibrium model (Bretschger and Zhang 2017), a systems dynamic model for the electricity supply security (Osorio and van Ackere 2016), the MERGE-ETL integrated assessment model (Marcucci and Turton 2012) and Prognos modelling framework (Prognos 2012). Although these studies demonstrated the technological feasibility of meeting stringent climate change mitigation targets, none of them assessed a scenario targeting below 2 °C global warming.

To this end, we employ an enhanced version of the Swiss-TIMES energy systems model (STEM) with a more detailed representation of the electricity sector, given the central role of electricity in meeting ambitious climate change mitigation goals. The model includes a range of features suitable for an in-depth analysis of decarbonisation pathways, such as: (a) early capacity retirement mechanisms to evaluate stranded assets; (b) electricity grid topology to assess challenges in the electricity infrastructure; (c) representation of the stochastic variability of renewable sources; and (d) modelling of ancillary services markets.

2 Methodology

2.1 *The Swiss TIMES Energy Systems Model*

The Swiss TIMES energy systems model (Kannan and Turton 2014) has a long-term horizon (2010–2100) with 288 hourly intra-annual timeslices (four seasons and three typical days per season). It covers the whole Swiss energy system with a broad suite of energy and emission commodities, technologies and infrastructure, from resource supply to energy conversion and usage in 17 energy demand sectors (Fig. 1).

The electricity sector of the model has been enhanced, due to the central role of electricity in the decarbonisation. There is a representation of four electricity grid levels, from very high to low voltage, to which different power plant and storage options are connected (Panos and Kannan 2016). Technical operating constraints of the hydrothermal power plants are approximated via a linearised formulation of the unit commitment problem (Panos and Lehtilä 2016). The power plants can be retired before the end of their technical lifetime when they have higher fixed or operating costs than the investment cost in new technology (Lehtilä and Noble 2011). The stochastic variability of electricity supply and demand is calculated from a bootstrapped sample of weather and consumption data in Switzerland over the last 15 years (Fuchs et al. 2017). The concept of the stochastic residual load duration curve (RLDC) is then employed to assess the needs in storage and dispatchable generation capacity (Lehtilä et al. 2014). The requirements in capacity for primary

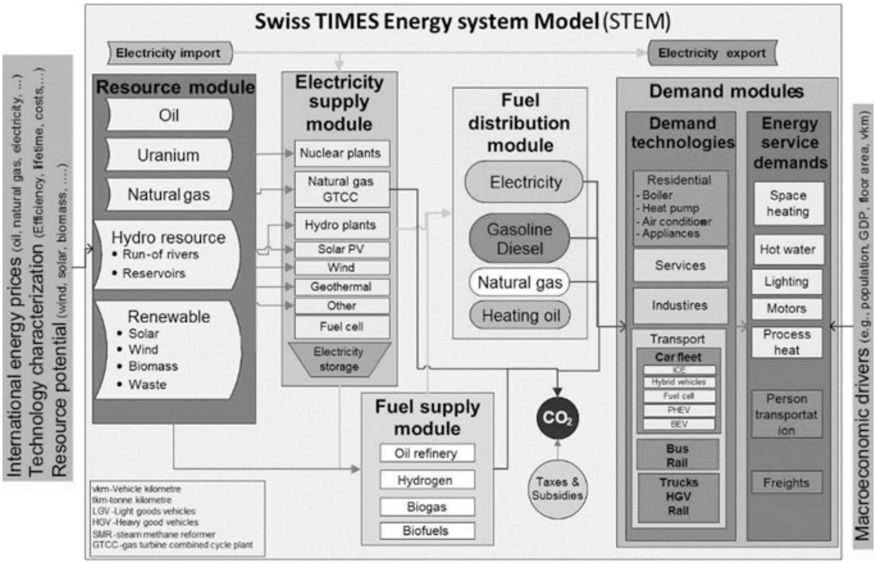

Fig. 1 Overview of the Swiss TIMES energy systems model (STEM)

and secondary reserve are endogenously modelled via ancillary services markets (Fuchs et al. 2017; Panos and Kannan 2016; Welsch et al. 2015).

The model includes an ad hoc representation of the electricity grid transmission topology with fifteen grid nodes. Seven Swiss regions are represented as a single node each. Each of the four existing nuclear power plants and each one of the four neighbouring countries is also represented as a single node. A power flow model (Schlecht and Weigt 2014) is employed to aggregate the detailed electricity transmission grid into the 15 nodes and 319 bi-directional lines included in the STEM model (Fuchs et al. 2017; Lehtilä and Giannakidis 2013).

Because of these enhancements, the transport sector is not endogenously modelled to reduce the model's equation matrix. The demand for transport fuels is exogenously provided based on the Swiss energy strategy scenarios (Mathys and Justen 2016; Prognos 2012). The rationale for excluding the transport sector from this study is that mobility choices of the individuals are not always cost-optimal. They are also based on other non-cost related factors (e.g. comfort), which are not adequately represented in the TIMES modelling framework and are subject to additional research (Daly et al. 2015).

2.2 Definition of the Baseline and Low Carbon Scenarios

The chapter assesses two scenarios, differentiated by the level of the climate change mitigation effort and the exogenously provided fuel consumption in transport. The Baseline scenario is considered to be compatible with the Swiss commitments, while the Low Carbon scenario is a deep decarbonisation scenario. The definition of the Low Carbon scenario is based on the post-2015 CO_2 budget that limits the warming to 1.5 °C.

The STEM model considers energy-related CO_2 emissions. We assume that the CO_2 emissions from industrial processes decrease according to the CO_2 emissions from fuel combustion in both scenarios, based on the reduction in the future cement production (Prognos 2012) and the implementation of emission savings measures (Zuberi and Patel 2017). Since we use the post-2015 global CO_2 emissions budget, we do not impose additional assumptions regarding the abatement of the non-CO_2 Kyoto protocol gases.

2.2.1 The Baseline Scenario

The energy service demands are derived from the macroeconomic developments and the efficiency measures assumed in the Politische Massnahmen (POM) scenario of the Swiss Energy Strategy (Prognos 2012). The main assumptions are summarised in Table 1. The Baseline scenario implements the Swiss commitments to UNFCCC, and it can be considered as the "NDC" scenario. Hence, based on domestic measures only, the scenario achieves a 30% reduction in the CO_2

emissions by 2030 from 1990 (UNFCCC 2015). In 2050, the CO_2 emissions decline by at least 42% from 1990, equivalent to the minimum target of 70% with the same ratio between domestic measures and international credits as in 2030.

2.2.2 The Low Carbon Scenario

The energy service demands, technology assumptions and resource availability are the same as in the Baseline scenario. The fuel consumption in transport is derived from the Neue Energie Politik (NEP) scenario of the Swiss energy strategy (Prognos 2012), which is compatible with the long-term Swiss target of 1–1.5 t-CO_2 per capita.

Table 1 Main assumptions in the “Baseline” scenario

	2010	2030	2050
Economy/demography			
Real GDP (billion CHF_{2010})	546.6	670.5	800.7
Population (million)	7.9	8.8	9.0
Space heating area (million m^2)	708.8	863.2	937.5
Renewable energy potentials			
Hydropower (TWh_e)			39.0
Solar PV rooftop (TWh_e)			19.2
Wind (TWh_e)			4.3
Geothermal (TWh_e)			4.4
Biomass (PJ_{th})			104.0
Imported fuel and CO_2 emissions trading scheme prices			
Swiss border gas price (CHF_{2010}/GJ)	7.9	11.0	13.2
Swiss border diesel price (CHF_{2010}/GJ)	16.4	21.0	25.4
CO_2 price (ETS, CHF_{2010}/t-CO_2)	15.0	48.0	59.0
Specific investment costs of key technologies (depending on size and application)			
Solar PV(CHF_{2010}/kW)		1400–2200	1000–1400
Heat pumps (CHF_{2010}/kW)		400–2700	400–2200
CHP gas CHF_{2010}/kW_e)		1200–6100	1200–5900
Efficiency measures			
Buildings: Labelling, renovation, oil-heating replacement, new building construction codes			
Industry/commercial: Efficiency incentives in industrial processes, ORC, best available technologies			
Power sector			
Nuclear phase-out by 2034, CO_2 capture and storage is not available, electricity net imports are allowed, grid expansion limited to the already announced plans for 2025 and beyond by the Swissgrid			

Sources Prognos (2012), Bauer and Hirschberg (2017), IEA (2016), Panos and Kannan (2016) and own estimations
Exchange rate: 1 CHF2010 = 0.96 USD2010 = 0.72 EUR2010

The emission reduction trajectory is based on the post-2015 Swiss CO_2 budget, derived from a per capita allocation of the global post-2015 CO_2 budget by using the medium fertility population projections (UN 2017b). Starting from a global post-2015 CO_2 budget of 250 GtC that limits warming to 1.5 °C with 66% probability by assuming adaptive mitigation of non-CO_2 climate drivers (Millar et al. 2017), the Swiss post-2015 budget is about 860 Mt CO_2. The trajectory imposes CO_2 emission reduction targets relative to 1990 of 50% in 2030, 70% in 2040 and 85% in 2050, which have to be achieved domestically and without carbon dioxide removal technologies. The post-2050 Swiss CO_2 budget is then 93 Mt CO_2, and it requires zero emissions by 2085 and cumulative negative emissions of 8 Mt CO_2 thereafter.

The scenario achieves 0.7 t-CO_2 per capita in Switzerland by the year of 2050, which is below than the world average and close to the OECD and EU average in the Beyond 2 °C Scenario (B2DS) of the IEA (IEA 2017). It could be argued that the Low Carbon scenario falls within the Paris Agreement range of ambition.

3 Results and Policy Recommendations

Moving beyond NDC requires fast and deep CO_2 emissions reductions. The emissions peak in 2020 in both scenarios, but the cumulative carbon budget over the period to 2050 is about 33% lower in the Low Carbon scenario than in Baseline (Fig. 2). In the Low Carbon scenario, emissions decline at rates exceeding past increases and accelerating to reach 5.6%/yr. after 2030. The transport and buildings sectors lead the way in the shift from the Baseline to the Low Carbon scenario, accounting for one-third each of the incremental cumulative abatement over the period of 2015–2050. Increased electrification in the end-use sectors sees the power sector absorb increased demand in the Low Carbon scenario while delivering about one-fifth of the additional abatement due to the deployment of new renewable technologies. Energy conservation also has an essential role to play, contributing to 19% of the mitigation in 2050.

3.1 Transforming the Electricity System

Consumers are turned into prosumers facilitated by digitalisation. While in the Baseline scenario the existing nuclear generation is mainly replaced by large gas power plants, in the Low Carbon scenario the electricity sector undergoes a profound restructuring towards renewable generation. In this scenario, renewables contribute about 90% to the total electricity supply by 2050 (Fig. 3). Decentralised electricity supply sources (combined heat and power CHP and photovoltaic PV) and prosumers, i.e. consumers that are also producers, are important in both scenarios. A large part (up to 85%) of decentralised electricity generated in the

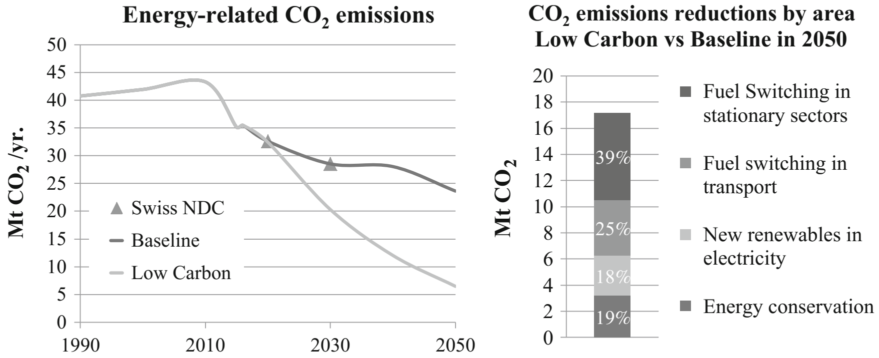

Fig. 2 Direct CO_2 emissions from fuel combustion (excluding international aviation) and emissions reductions from baseline by technology area

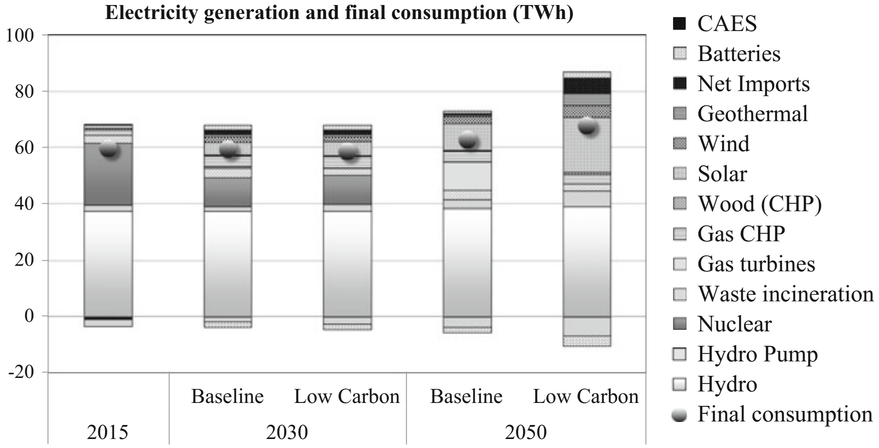

Fig. 3 Electricity generation mix (negative values denote charging of electricity storage)

residential sector is consumed on-site. The opposite holds in the commercial sector, driven by the larger installations.

Digitalisation helps in integrating variable and distributed energy sources in the future electricity markets. Better data and rigorous analysis of consumption and production patterns are essential. However, regulatory frameworks are needed regarding data collection and storage, connectivity and privacy. Similar concerns hold in other countries too, such as Denmark, Sweden and Germany.

High voltage networks need to support distributed generation. The share of distributed generation in end-use sectors increases from 27% in the Baseline scenario to 41% in the Low Carbon scenario by 2050. New connection requests at the lower grid levels lead to structural congestion in the upper levels. In order to eliminate congestion, the transmission grid has to be expanded beyond the announced plans from the Swiss Transmission System Operator (von Kupsch 2015). Since grid expansion requires long run-in times to be implemented and must achieve acceptance by public and stakeholders, early dialogue, planning and action are necessary. Similar issues are also faced by other European countries, such as Germany.

Microgrids and virtual power plants are the new business models for flexibility. The future Swiss energy system needs a profound technological shift towards flexibility. The uptake of variable renewable energy in the Low Carbon scenario increases the requirement for secondary reserve capacity to 700 MW in 2050, from 400 MW in 2015, with the peak demand for reserve occurring in summer instead of winter. Hydropower remains the main reserve provider, but the opening of the ancillary markets to smaller units owned by consumers is required to meet the increased demand. Flexible CHP units and storage increase their role in grid balancing in the Low Carbon scenario and provide by at most 200 MW of reserve.

New business models emerge involving the evolution of microgrids and virtual power plants. Utilities could be smart energy integrators that operate the distribution of electricity but no longer own generation units. Alternatively, utilities could deal directly with customers and sell services such as heat, lighting and cooling. An internet of energy could appear as new software platforms need to be developed to remotely, securely, and automatically dispatch generation and storage units in a web-connected system. This opportunity encapsulates the challenge for policy-makers to create regulatory frameworks that ensure privacy and security. Most of the developed European countries face similar challenges today.

Storage helps in achieving ambitious climate change mitigation goals. Accelerated deployment of storage, driven by the hedging against the increased variability of supply and arbitrage with the hourly electricity prices, is a crucial enabler in supporting the transition to a low-carbon power system. The lion’s share in the future stationary electricity storage is in batteries (Fig. 4). About 6 GW of additional capacity in batteries is required in the Low Carbon scenario by 2050. Batteries complement pump storage when hydro storage is unavailable (due to water restrictions or participation in ancillary markets) and locally balance the electricity supply and demand.

The operation of pumped hydro storage correlates with cross-border prices arbitrage. Economic benefits also occur for consumers through load shifts via batteries. However, regulatory reform and development of balanced approaches are essential to facilitate the penetration of behind the meter storage options. These insights could also be useful to countries with substantial hydro storage resources such as Norway, Sweden and Austria.

Power-to-gas technologies become commercial and generate clean fuels. Generation of hydrogen and methane from electrolysis with renewable electricity becomes commercial only in the Low Carbon scenario. About 28% of the variable renewable electricity generated in summer in 2050 enters into the power-to-gas pathway, and more than half of it is seasonally shifted (Fig. 5).

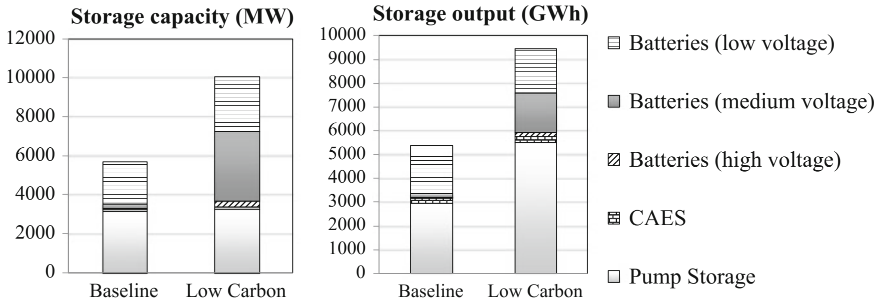

Fig. 4 Electricity storage capacity and production (stationary applications) in 2050

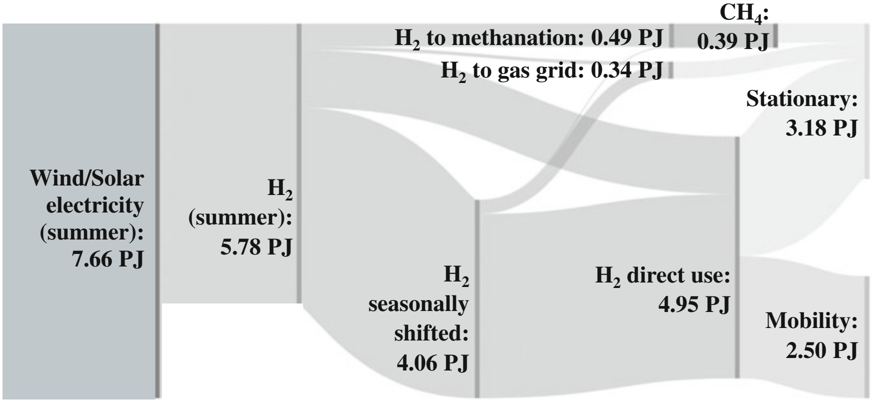

Fig. 5 Electricity production during summer that enters into the power-to-X pathway in 2050 (PJ/yr.) in the low carbon scenario

The power-to-gas technologies promise clean fuels for heating and mobility sectors but require a policy and regulatory framework. If supported by taxation incentives, requirements regarding the share of renewable fuels at the distribution levels, renewable fuels certification schemes, and subsidies, these technologies could be scaled up quickly once successfully demonstrated. For example, pilot projects in Belgium, Germany and Iceland have already reached the demonstration phase and can be scaled up with sufficient policy support (EC 2017).

3.2 Advancing the Low-Carbon Transition in End-Use Sectors

Electricity and energy efficiency play a predominant role in the decarbonisation. Electrification of the demand increases from 40% in the Baseline scenario to

60% in the Low Carbon scenario in 2050, where, oil and gas are phased-out, with residual uses of oil in transport and small-scale gas applications in industrial heating remaining by 2050. In contrast, heat produced from CHPs and heat produced from renewable sources account together for more than one-fourth of final energy consumption in 2050 (Fig. 6). Moreover, the final energy consumption in the Low Carbon scenario declines by 25% compared to the Baseline scenario in 2050. The deep decarbonisation pathway to 2050 comprises of rapid and aggressive deployment of highly efficient end-use technologies and rigorous application of energy codes and efficiency standards in all sectors. The insights from this subsection apply to many European countries.

Unlocking the energy savings potential in the buildings sector requires long-term and consistent price signals. The Low Carbon scenario requires a critical shift away from fossil fuels and moving towards close to zero emissions and efficient buildings. Heat pumps (60% in the total heat supply in buildings by 2050), renewables (21%), cogeneration and district heating (15%) and building renovation and insulation measures beyond the Baseline scenario are essential.

For this to happen, a comprehensive policy needs to be carefully designed, and unprecedented action needs to be taken to overcome economic barriers. Such barriers include unnecessary costs or early retirements of existing capital (e.g. the recent installations of gas-based heating equipment), and the high upfront capital costs of heat pumps, building conservation measures and solar PV. Since the insulation measures are not cost-efficient in the medium term, the concept of the efficient and close-to-zero emissions community could create economies of scale by implementing deep energy renovations across entire building blocks and therefore lower the costs and attract stakeholders. It could also be applied in managing and

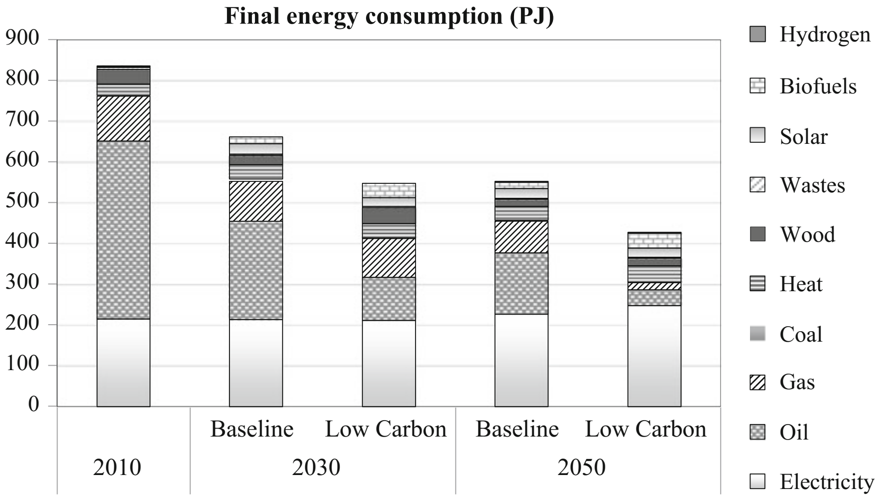

Fig. 6 Final energy consumption in industry, residential, commercial and transport

optimising the energy loads in buildings, allowing the shifting of electricity and heat loads relative to peak periods of demand.

Industry calls for energy and material efficiency strategies. The cumulative CO_2 emissions from industry over the period of 2020–2050 decline from 190 Mt in the Baseline to 140 Mt in the Low Carbon scenario. More than 70% of this reduction is attributable to the direct technology change, fuel and feedstock switching. The rest is attributable to additional energy conservation measures that reduce the energy service demands.

Energy efficiency and best available technologies (BAT) play a critical role in the decarbonisation of the industrial sectors. Implementation of energy management standards (e.g. ISO 50001) and process integration with the goal of minimising fuel consumption and emissions should be a priority. Public-private and cross-sectoral partnerships could efficiently be used to design and deploy integrated solutions. Moreover, material efficiency strategies should be further encouraged through price signals reflecting the energy and CO_2 footprint of production. Consumers should be made aware of this to avoid wasting materials, and the re-use of post-consumer scrap could be increased by implementing deposit refunding schemes upon product return. Improvement of the recycling rates and valorisation for electricity and heat production instead of landfill disposal could also help in achieving higher efficiency in materials usage.

Sustainable transport is a formidable task due to limited domestic clean fuels. The cumulative CO_2 emissions from the transport sector are about one-third less in the Low Carbon scenario compared to the Baseline over the period of 2020–2050. Much of this reduction is attributable to biofuels and electricity, which account for one-third each of the final energy consumption in transport by 2050. Because of environmental and food security concerns, the domestic biofuel production is limited (Steubing et al. 2010), and more than 95% of the biofuels in transport are imported (Prognos 2012). The decarbonisation of the transport sector also requires changing the nature and structure of transport demand, significant improvements in efficiency, policies and measures that increase the share of public transport modes and optimise freight transport (Prognos 2012).

Demand side management is a crucial pillar of a low carbon energy system. Temporal shifts of the electricity in electric-based heating systems on different hours of consumption and heat supply occur in both scenarios (up to 13% of total electricity in 2050). They are driven by congestion and arbitrage in heat supply costs. The shifts are enabled by water heaters and heat pumps (Fig. 7) and result in economic benefits for consumers due to the use of less energy in peak hours.

Such an active demand side management implies an awareness of the consumers to real-time prices, enabled through smart grids, monitoring and control systems, as well as aggregation of demand response and virtual power plants. However, the scalability of these new business models and the amount of flexibility that they can deliver remains uncertain.

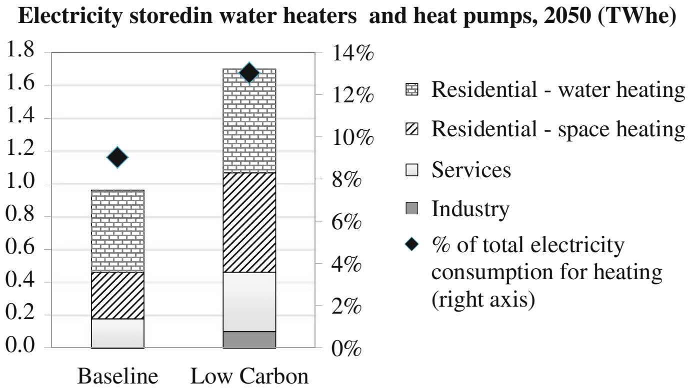

Fig. 7 Amount of electricity shifted to different consumption hours via water heaters and heat pumps by 2050

3.3 *The Cost for the Transition to a Low Carbon Energy System*

A well-designed carbon price is part of the emission reduction strategy. The marginal cost per t CO_2 rises to 2150 CHF by 2050 (6 CHF/litre of light fuel oil), twice the carbon price projected in the NEP scenario of the Swiss Energy Strategy (Ecoplan 2012). It reflects the limited availability of low-carbon resources and the weak behavioural response of the high-income economic agents to a given price level. Carbon prices incentivise investment changes and can be introduced in different ways (e.g. carbon tax, cap-and-trade, credits). However, the carbon pricing mechanisms take time to develop, and policymakers need to establish an enabling environment and regulatory frameworks. Nonetheless, carbon prices are a source of government revenue, offer a good tax base that is difficult to evade, and can help offset economic burden via recycling (Stiglitz et al. 2017). International coordination can help avoid carbon leakages between countries with different carbon price levels and lower the overall cost of reducing emissions.

Investment lock-in creates stranded assets, and early action is necessary. In the Low Carbon scenario, about 1.6 GW of large gas power plants (90% of the 1.8 GW investment made in 2040) are retired before their technical lifetime over 2015–2050 (the remaining 200 MW contribute to secondary reserve). This is ten times more than in the Baseline. The early replacement of fossil-based heating supply in the Low Carbon scenario is twice the one in the Baseline.

Going beyond the NDC with only domestic emission reduction measures exponentially increases the per capita climate change policy costs by 2050. The average annual policy cost per capita (discounted at a 2.5% social rate), by excluding the transport sector, increases from 280 CHF/yr. in 2030 (less than 1% of GDP/capita) to 1780 CHF/yr. in 2050 (around 5% of GDP/capita) (Fig. 8). The scale of effort required indicates that the gap between the current Swiss

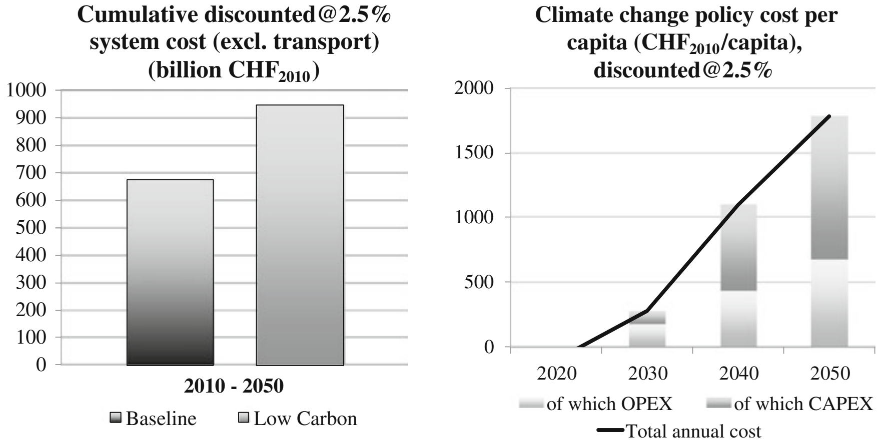

Fig. 8 Discounted system cost and policy costs per capita (electricity generation and heating sectors only, the transport sector is excluded)—1 CHF$_{2010}$ = 0.96 USD$_{2010}$ = 0.72 EUR$_{2010}$

commitments and the pathway to ambitious emissions reductions with domestic measures is immense. To this end, the current Swiss energy strategy is largely aiming to mitigate some of the CO_2 emissions outside Switzerland, including know-how and capital transfers to developing countries with lower mitigation costs. Such supporting mechanisms could also indirectly facilitate energy access in the developing countries and contribute to the broader global sustainable development goals (UN 2017a).

The daunting task is to mitigate emissions in heating supply. Total capital investments are almost tripled under ambitious climate change mitigation targets compared to Baseline. Capital expenditures in stationary sectors are twice those in

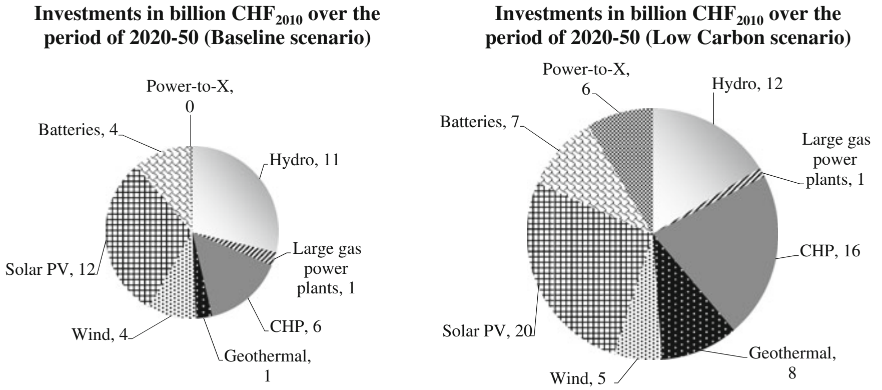

Fig. 9 Cumulative investment, discounted@2.5%, in key technologies for electricity supply (1 CHF$_{2010}$ = 0.96 USD$_{2010}$ = 0.72 EUR$_{2010}$)

electricity supply, driven by the increase of investments in heat pumps in the buildings sector. Moreover, the emerged new business models shift capital from large-scale electricity generation technologies to storage and distributed generation (Fig. 9).

4 Conclusion

In this chapter, we assessed the technical feasibility of the Swiss climate change mitigation pledges, by taking into account the main pillars of the Swiss energy strategy: gradual nuclear phase-out, energy efficiency gains, and increased penetration of renewable energy. The shift to a below 2 °C pathway would require faster and deeper CO_2 emission reductions across both the energy supply and demand sectors than the current Swiss national determined contribution. Several of the insights and policy recommendations would be valid beyond the Swiss case.

The power sector undergoes a profound restructuring towards distributed renewable generation. Prosumers, microgrids, virtual power plants and storage are key components of the future low-carbon electricity supply and shift the transformation focus on integration rather than supply-side. Grid reinforcement and market reforming, not based on marginal cost pricing, are necessary and strong carbon pricing policies are needed backed-up with technology support measures to reduce investment risks.

Efficiency is crucial for achieving deep emission cuts in the end-use sectors. The energy saving potential in buildings is vast, but it requires a stronger involvement from the buildings-related stakeholders as in many cases owners may not reap the full benefits. Efficient and close-to-zero emissions communities could be an opportunity to create economies of scale in deep energy renovation across entire building blocks.

Since the Swiss NDC in the Baseline scenario already harvests the “low-hanging fruits” in the emission reductions in industry, promotion of best available technologies, fuel and feedstock switching, process integration, implementation of performance standards and material usage efficiency are required to achieve the additional emission cuts in a below 2 °C pathway. Price signals should be incorporated into consumer products related to environmental externalities of materials, to increase the collection, recycling and reuse of post-consumer scrap.

The additional abatement of the CO_2 emissions in the transport sector requires shifts in individual mobility behaviour and optimisation of freight transport. An important challenge for Switzerland is the limited domestic clean energy carriers, and the absence of a large research activity that explores ways in achieving the decarbonisation of the transport sector. Power-to-gas technologies can help in transforming excess renewable electricity into clean fuels for the heating and transport sector, but their commercialisation needs further policy support, and appropriate regulatory frameworks enabling these new business models.

Finally, while the Swiss energy strategy aims at mitigating some of the CO_2 emissions outside Switzerland, in developing countries with lower abatement costs, negative domestic emissions could be inevitable in the longer term. In this regard, policymakers should also work towards the development of appropriate legislation for carbon capture, transmission and storage.

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