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The Green Light or the Green Line?
Challenges Facing the Energy Choices for Switzerland

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Abstract

For most of its history, even though Switzerland has relied on imported fossil fuels to meet its energy needs, low-carbon energy sources such as hydropower and nuclear power have been at the forefront of the electricity generation sector for the last 50 years. However, after the Fukushima nuclear accident in 2011, Switzerland decided to phase out nuclear energy by 2034 through the "Energy Strategy 2050", a national plan adopted in 2017 that represents a structural break in its energy pattern. Compared to Germany, Switzerland has chosen a less environmentally harmful but more risky strategy, which consists of limiting the substitution of nuclear energy with fossil fuel energy sources, while filling the gap created by the progressive nuclear phase-out through the massive development of alternative and renewable energy sources in the long term. Facing this "green challenge", Switzerland would need to import electricity from European foreign suppliers. However, one missing element of this global reform appears in the transport sector, which still produces significant CO_2 emissions. Such historical constraint would undoubtedly affect Switzerland's energy security and independence patterns. However, the real challenge created by this nuclear phase-out may not be about becoming energy-independent, because such a deep transition necessitates important electricity imports, but rather about answering the growing electricity demand in the future and securing its energy supply, with the share of renewable energy sources becoming increasingly important. Indeed, Switzerland will have to deal with the trilemma of energy security, independence and sovereignty.

Keywords: Switzerland; ecology; sovereignty.

JEL Codes: Q 32; Q 42; Q 43.

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1. Introduction

Potential climate change threats, geopolitical tension and the recent nuclear accident of Fukushima in 2011 have triggered widespread concerns about the security and environmental impacts of the energy supply, which are associated with energy production and consumption. Consequently, several developed countries are currently proposing strong energy substitution policies and a radical energy transition strategy. This is the case in Germany, Japan, Belgium and Switzerland. All of these countries decided in 2011 to start or accelerate a nuclear phase-out for environmental or security reasons. Even though the date of the nuclear accident of Fukushima is seen as a turning point in energy choices for development, its effects on global energy policies differ from country to country. For instance, while Germany decided it would withdraw from nuclear energy dependence after 2022 through acceleration of the "EnergieWende" process (defined initially as "growth and prosperity without petroleum and uranium" by an environmental think tank in 1980; Krause et al., 1980), where fossil fuels such as coal and natural gas are used as substitutes for nuclear energy, Switzerland, for example, has made some interesting choices regarding new types of policy.

Indeed, Switzerland took the decision to plan the "Energy Strategy 2050". Following several debates after 2011, which resulted in a national referendum in 2017, the Swiss electorate approved a new energy law, which came into force on 1 January 2018. At first sight, such a legal change is likely to have the impact of a structural break in the national energy policy by creating a before and after 2018 situation in Switzerland. Specifically, by choosing to strongly limit its dependence on fossil energy during its transition, Switzerland projects that it will cease nuclear energy production after 2034 through a unique strategy involving the massive promotion of renewable energy sources on its territory. More broadly, at stake for Switzerland is its ability to reach energy independence and security in the long term. Independence here corresponds to domestic access to a variety of energy resources, which provide an alternative to imported energy resources. Reciprocally, according to Eurostat (2018), energy dependency shows the extent to which an economy relies on imports in order to meet its energy needs. Security refers to the national strategy, which consists of ensuring the procurement of energy for domestic and industrial needs. However, it does not necessarily rely on autarky. This could be done through domestic production but also through secured imports from a large number of foreign suppliers and safety energy agreements.

Therefore, on the issue of energy, as well as other dimensions such as industry and trade competitiveness in advanced sectors, the case of Switzerland is very relevant in many respects (Baranzini et al., 2013). Indeed, while the country is one of the wealthiest (its GDP in purchasing power parity was approximately 64,649 US dollars in 2018 (IMF, 2019)), Switzerland was ranked ninth worldwide among the most industrialised[3] (Ponsot & Vallet, 2013) countries in the world, with several advanced technology sectors (the watch industry, the food industry and chemistry), and it finally topped the World Economic Forum's Global Competitiveness Index (GCI), which evaluates and compares the competitiveness of 144 economies. Switzerland is also one of the most progressive countries when it comes to the environment. Indeed:

i) Switzerland has the lowest carbon intensity of all 30 International Energy Agency (IEA) member states (International Energy Agency, 2019).

ii) With a score of 0.80, Switzerland topped the rankings for the EAPI in 2017 and was thus ranked first among more than 120 countries by the World Economic Forum (WEF) as the best "energy mix country" (Energy Architecture Performance Index Report presented by the World Economic Forum, 2017).

iii) The World Energy Council published an international report entitled "Policies for the Future: 2011 assessment of country energy and climate policies", which ranked Switzerland as the best country performer (with Sweden and France), according to an energy sustainability index for 2011 (World Energy Council, 2011).

iv) Finally, in 2011 Switzerland was identified as one of the most energy-efficient (and least energy-intensive) countries in the OECD (Filippini & Hunt, 2011).

Up to now, history has demonstrated that Switzerland has succeeded in combining a unique energy structure while benefiting from a high level of development. Such a "puzzle" is noticeable since Switzerland was a poor country before the end of the nineteenth century, transforming itself into a dynamic economy without relying on raw materials, apart from water (Bouquet, 2013; Church & Head, 2013). Specifically, Switzerland succeeded in the first two industrial revolutions during the nineteenth century without relying on domestic raw materials.

Therefore, at first sight, the country seems to be well prepared for adapting to climate change mitigation objectives, and for reaching the targeted energy independence and security. However, Switzerland has an "Achilles' heel", namely, that it still relies on imported fossil fuels to meet its energy needs. In addition to the ecological footprint that fossil fuels entail – in Switzerland, in 2013, the ecological footprint per capita was three times the average worldwide available bio capacity per capital because of the rise in energy consumption, particularly fossil energy (OFS, 2018, p. 49) – imported fossil fuels are associated with a dependency on other countries.

Such dependence also threatens the fulfilment of climate change mitigation objectives. Consequently, this policy decision to phase out nuclear generation threatens both climate change mitigation and supply security. According to the International Energy Agency (2019), filling the gap

3 In spite of the Global Financial Crisis, industrial production increased by approximately 26.8% between 2004 and 2016 (see OFS, 2018).

left by nuclear power closures while maintaining low carbon generation and high standards of energy supply security will be one of the challenges that Switzerland has to address in its long-term energy strategy. Thus, understanding how structural changes in the new Swiss energy policy will affect both its energy security and independence patterns would generate insights into some of the uncertainties associated with this deep transition and its consequences for Swiss sovereignty. However, as we shall explain later, these three goals cannot be completely achieved simultaneously. Therefore, preserving Swiss sovereignty seems to be a compromise between promoting the security of its energy supply and limiting its energy dependence on foreign suppliers.

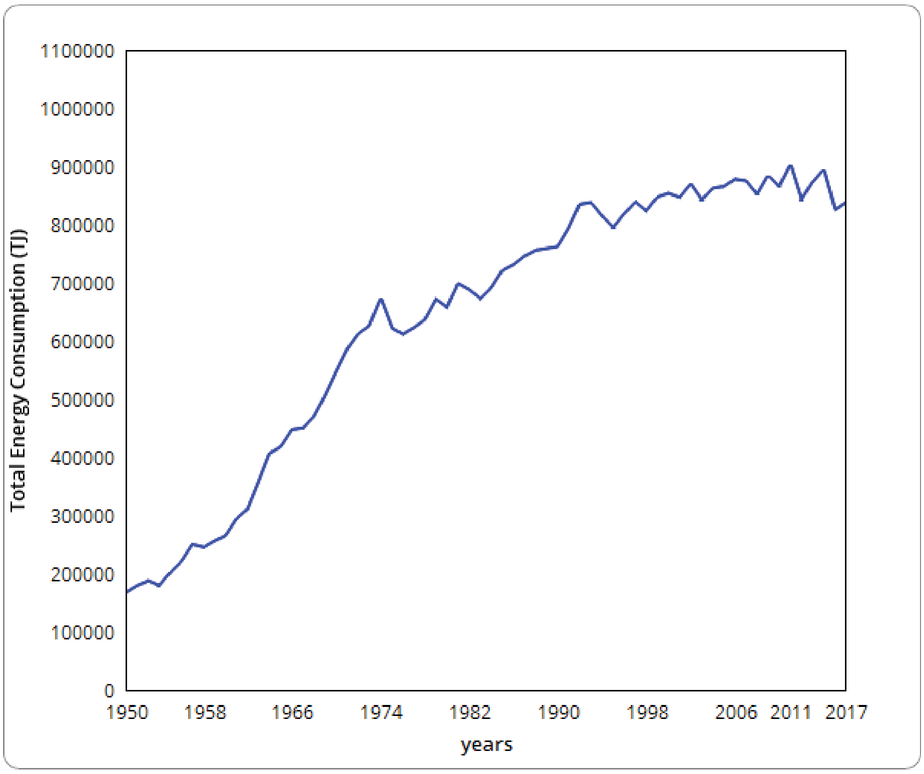
All in all, the Swiss case raises the following issue: To what extent will Switzerland's current and future climate change mitigation objectives allow the country to become more independent and more secure with respect to its consumption of energy?

The remainder of the paper is structured as follows. Section 2 provides a review of the global energy structure of Switzerland before 2018. In Section 3 we present an overview of the new energy structure of Switzerland after 2018, the date when the new energy law came into force as the policy instrument of "Energy Strategy 2050" following the Fukushima nuclear accident in 2011. Section 4 outlines the effects of this deep energy transition on Swiss energy security and independence. In addition, we tackle the Swiss energy sovereignty issue as the possible main determinant of the orientation of its new energy policy pattern. In section 5 we offer concluding remarks and some policy implications.

2) The Swiss energy structure before 2018

Since 1950 energy consumption has multiplied five times (Swiss Federal Office of Energy (SFOE), 2019). *Fig.1* shows the total energy consumption (TJ) for Switzerland during 1950–2017, which increased from 167,700 TJ to 849,790 TJ over this period. In addition, energy use per capita in 2015 was two times higher than in 1960, with an increase from 1,387 to 2,960 kg of oil equivalent per capita over this period (World Development Indicators (WDI), 2019). This change can first be explained by the increase in non-renewable energy consumption, notably natural gas and nuclear energy consumption, but also because of the significance that is still accorded to oil in total energy consumption. Second, it can be linked to the increase in renewable energy consumption, through the development of hydroelectricity since 1950, but also the surge in solar, wind and biomass use in recent years. According to the Swiss Federal Office of Energy (SFOE, 2017), the transport sector and households represented 36% and 28.2% of total energy consumption in 2016, respectively. Finally, 18.2% and 16.6% of total energy consumption corresponds to industry and services for the same year, respectively. The main sources of energy in Switzerland are oil, natural gas, hydropower and nuclear power. However, since 2005 Switzerland has seen a surge in the use of renewable energies such as biomass, wind power and solar power (Swiss Federal Office of Energy (SFOE), 2017).

Fig. 1: Total energy consumption (TJ) in Switzerland, 1950–2017



Source: constructed by the authors. Data were taken from the Swiss Federal Office of Energy (SFOE, 2019).

i) Fossil fuel energy

As mentioned in the Introduction, for most of its history, Switzerland has been a fossil-energy-poor state, relying almost completely on imported fossil fuels to meet its energy needs. Apart from water and wood, Switzerland has no natural resources of its own. Consequently, because fossil fuel energy sources dominate Switzerland's energy mix, it must rely on important oil and natural gas imports. According to the World Development Indicators (WDI, 2019), Switzerland imported 50.1% of its total energy use in 2015 (against 78.7% in 1970): mainly oil, natural gas, coal and uranium for its nuclear activity. Thus, imports of oil and natural gas accounted for roughly two-thirds of the final energy demand in 2014 (Swiss Federal Office of Energy (SFOE), 2014) and 5% of total merchandise imports in 2015 (World Development Indicators, 2019). The share of fossil fuel in total energy consumption decreased from 1970 (82%) but was still significant (50.2% in 2015) (World Development Indicators, 2019). At the disaggregated level, the share of both oil and gas in total energy consumption corresponded to 39% and 11% of total energy consumption in 2015, respectively. Moreover, the share of coal in total final energy consumption is insignificant (Swiss Federal Office for Energy (SFOE), 2019). *Fig. 2* shows oil, natural gas and coal consumption for

Switzerland over the period 1970–2017. We can observe that both oil and coal consumption decreased during the sample period, whereas natural gas consumption increased. However, the share of oil consumption in total fossil fuel consumption remains high and dominant. According to the British Petroleum Statistical Review (BPSR, 2019), oil consumption decreased from 12.9 to 10.9 million metric tons of oil equivalent over the period 1970–2017, while natural gas consumption increased from 0.03 to 2.7 million metric tons of oil equivalent over the same period, thus multiplying by 3. Finally, coal consumption decreased from 0.7 to 0.1 million metric tons of oil equivalent over the period 1970–2017.

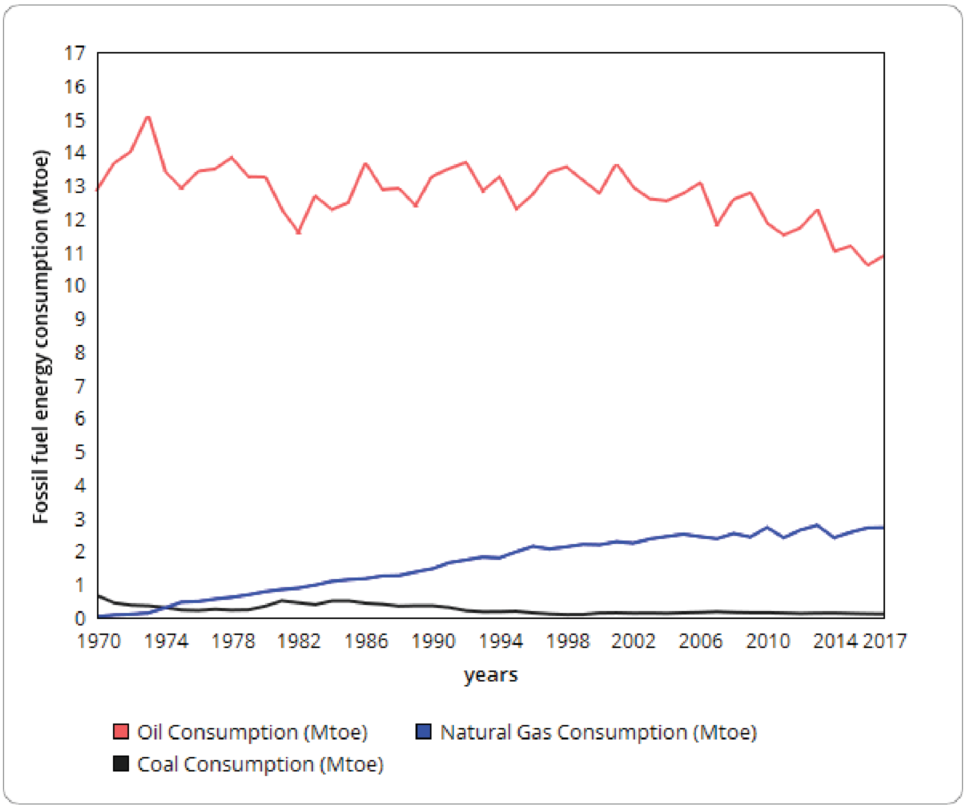
(1) Oil

The petrol imported to Switzerland came mainly from Nigeria and Kazakhstan, with a share in total imports of oil in Switzerland of 33% and 16%, respectively; and this trend seems to be continuing. In 2017, in Switzerland, the share of oil in total oil imports from Nigeria and Kazakhstan reached 45% and 45%, respectively. This is equivalent to saying that in 2017 Switzerland imported 90% of its oil from only two countries. In terms of oil consumption by sector, the transport sector represented 56% of total oil consumption in 2015 (World Development Indicators (WDI), 2019), followed by the residential sector, which represented 22% of total oil consumption in the same year (World Development Indicators (WDI), 2019).

(2) Natural gas

According to the Energy Statistics Report (ESR, 2016), Switzerland also has natural gas reserves, but in most cases, these are too small to justify exploitation. The only exception is Finsterwald (Lucerne), where a total volume of 73 million cubic meters (the equivalent of around 3% of Switzerland's annual gas consumption) was exploited between 1985 and 1994, which means that Switzerland's gas requirements have to be met entirely through imports. The natural gas supply to Switzerland is guaranteed thanks to a large number of suppliers from diversified geographic locations. In total, 95% of the gas consumed in Switzerland is produced in The Netherlands, Russia, Norway, Germany and Algeria, and 74% of the natural gas used is supplied by Western Europe (The Netherlands, Germany and Norway). This explains the fact that Switzerland is already connected to the European market of natural gas through 12 cross-border supply routes. Finally, at sectoral level, households represent the largest consumer group of natural gas, with a share of around 40%, followed by the industrial sector, with around 33% (Energy Statistics Report (ESR), 2016).

Fig. 2: Fossil fuel energy consumption in Switzerland (Mtoe), 1970–2017



Source: constructed by the authors with data from British Petroleum Statistical Review (BPSR, 2019).

ii) Renewable energy

As a country possessing few raw materials, Switzerland has no direct access to fossil energy carriers and nuclear fossil fuels and has to rely on importing them. It can, however, in different fields of renewable energy make use of sources available within the country in order to generate electricity. According to the Word Development Indicators (WDI, 2019), renewable energies covered approximately 25.3% of the final energy consumption in 2015 in Switzerland, which was much higher than in 1990 (17.1%). Consequently, Switzerland was ranked first among more than 120 countries by the World Economic Forum (WEF) as the best "energy mix country" in 2015. This decision was based on three criteria. First, the contribution of energy to economic growth, which corresponds to improvement in energy intensity. Second, the environmental impact of energy consumption, which corresponds to a reduction in carbon emissions. And, third, the accessibility and diversity of procurement, which concerns the limitations of energy dependency on foreign suppliers, the promotion of diversity in the energy supply, and the improvement of national energy security. Three main forms of renewable sources are concerned: energy from wind and solar; energy from waste incineration and biomass (wood); and energy from hydropower.

(1) Wind, solar and biomass (wood) and waste incineration

In 2014, in Switzerland, there were 37 wind farms with a total output of 100 gigawatt hours (Gwh) of electricity per year (Energy Statistics Report (ESR), 2016). The share of wind in total electricity generation is approximately 0.2% (2015), which is still not significant (Swiss Confederation, 2019). Even though solar power currently does not occupy a dominant place in electricity generation in Switzerland, with a share of 2.8% (in 2015), solar power is considered to be the biggest source of power potential in Switzerland for the future (Swiss Federal Office of Energy (SFOE), 2019). According to the Energy Statistics Report (ESR, 2016), by 2050 it would be possible to meet around 20% of the current level of national electricity demand through the use of photovoltaic systems. In addition, others are more optimistic, such as Future Energy Efficient Buildings & Districts (FEEBD, 2019), which considers that solar power will be able to ensure 27.2% of electricity production by 2050. Consequently, the future looks bright, since it is thought that solar power will be able to provide a considerable share of the future electricity demand. Finally, waste incineration and biomass (wood) represented 11% and 16.4% of domestic energy production, respectively, in 2015 (Swiss Confederation, 2019). With more than 23% of total energy consumption in 2015, Switzerland was largely higher than the European average for that year, at 16.7% (World Development Indicators, 2019). However, Switzerland remains lower than other renewable advanced economies such as Finland (39.3%), Sweden (53.9%) and Norway (69.4%).

(2) Hydropower

Switzerland has ideal conditions for the utilisation of hydropower, which is why this is its primary electricity generation source, with 57.9% in 2015 (World Development Indicators, 2019). According to the Energy Statistics Report (2016), hydropower remains Switzerland's most important domestic source of renewable energy. Because of the growing place dedicated to nuclear energy sources after 1970, the share of hydropower in electricity generation has been decreasing since 1960 when hydropower represented 99.1% of electricity generation. There are currently 658 hydropower plants in Switzerland that had a capacity of at least 300 kilowatts in 2016, producing on average 36,449 Gwh of electricity (Swiss Federal Office of Energy (SFOE), 2018). In terms of absolute value, hydropower consumption increased from 5.5 to 7.7 million metric tons of oil equivalent over the period 1965–2017 (British Petroleum Statistical Review (BPSR), 2019). However, electricity from hydropower has been particularly volatile across the years and seasons, which explains the energy security reasons that have led to the Swiss government developing an alternative electricity source, such as nuclear, in the past. Considering that the electricity demand has multiplied six times since 1950 (Enerdata, 2019), phasing out nuclear power through an expansion of hydropower is heavily criticised because of the growing energy demand and the limited hydropower potential in

Switzerland, which is currently exploited at 95%. According to the World Development Indicators (WDI, 2019), electricity production from renewable sources (wind, solar, biomass) is insignificant. By excluding hydroelectric, it only increased from 0.4% to 4.3% during 1980–2015. Developing alternative and renewable energies such as wind, solar and biomass appears crucial for the future.

iii) Nuclear energy

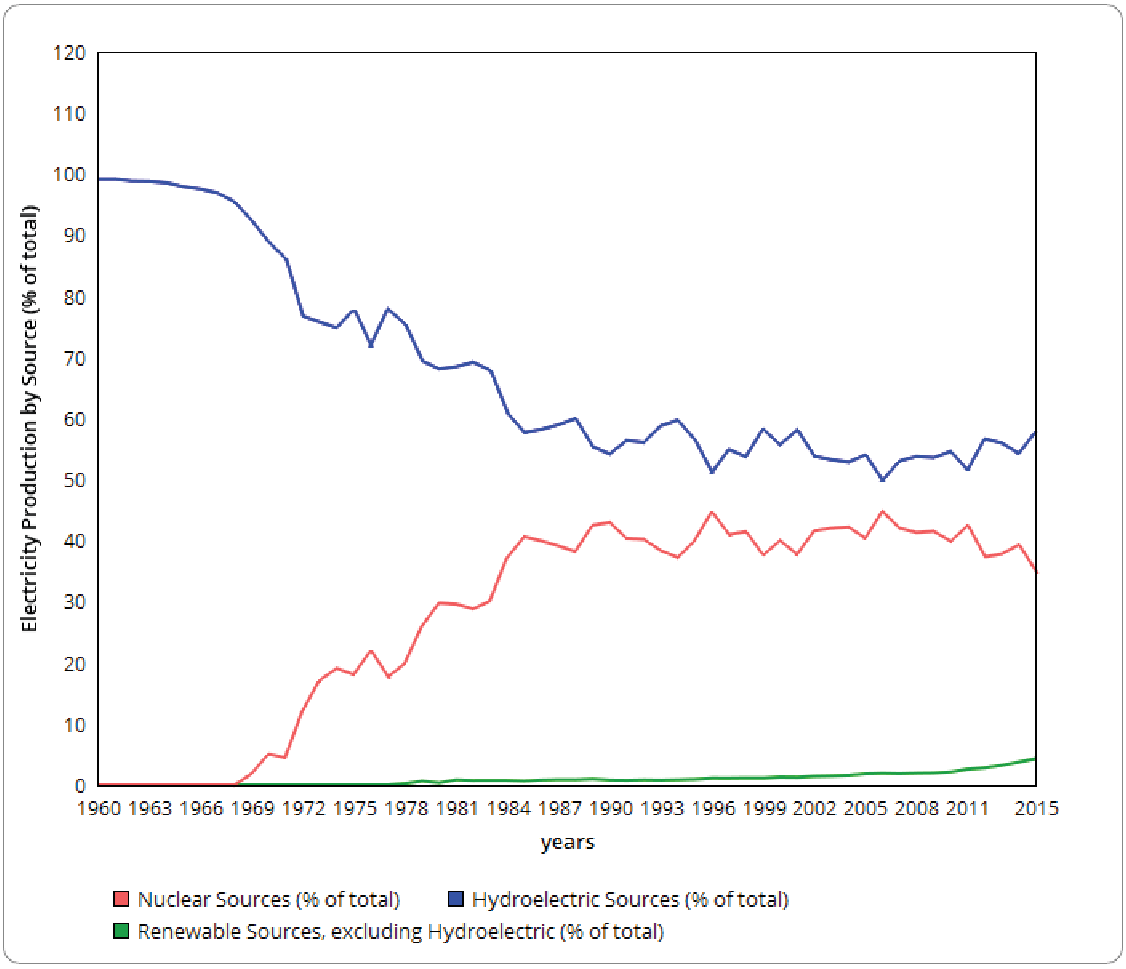
Nuclear power is the second largest electricity source in Switzerland. Its development began in 1969 with the Beznau I nuclear power plants, followed by Beznau II (1971), Mühleberg (1971), Gösgen (1979) and Leibstadt (1984). In 2015 nuclear energy consumption from the five national nuclear reactors represented 22% of total energy consumption (Swiss Federal Office of Energy (SFOE), 2016). In terms of absolute value, nuclear energy consumption increased from 3.3 to 5.8 million metric tons of oil equivalent during 1980–2017, with a turning point at 6.3 million metric tons of oil equivalent in 2007 (Bristish Petroleum Statistical Review (BPSR), 2019). According to the World Development Indicators (WDI, 2019), the share of nuclear energy in total electricity production increased from 5.1% to 44.8% of total electricity generation over the period 1970–2006. However, after 2006 it decreased from 44.8% to 32% of total electricity generation in 2017 (World Nuclear Association (WNA), 2019). And following Switzerland's decision to phase out nuclear energy by 2034, this trend is expected to reinforce itself in future.

iv) Electricity generation in Switzerland

Since 1950 electricity consumption in Switzerland has multiplied six times, with an increase from 31,780 TJ to 210,540 TJ over the period 1950–2017 (Swiss Federal Office of Energy (SFOE), 2019). On the demand side, the main demand comes from households (31.8%), industrial production (31.4%) and services (27%), and transport accounts for 8.1% of demand. The remaining part is consumed by agriculture and others. On the supply side, the electricity sector in Switzerland is considered to be unique, because almost the total amount of electricity was generated by both hydropower (56%) and nuclear power (38%) in 2014. The remaining 6% was mainly produced by renewable sources. *Fig. 3* shows electricity production by source (in % of total) for Switzerland over the period 1960–2015. Even if the dominant place accorded to hydroelectric generation since 1960 has been unquestionable, notice that nuclear energy has also assumed an important place in electricity generation. However, this trend appeared to stagnate and even slightly decrease after 2011 (the date of the Fukushima Nuclear Accident). In addition, electricity production from renewable sources, excluding hydroelectricity, appears to have grown over the years, but it is still insignificant compared to nuclear and hydroelectric sources.

The Swiss electric production model came into existence at the end of the nineteenth century in two ways. First, Swiss municipalities played a significant role when the electrification process was launched in the 1870s. Since municipalities were already involved in the production and distribution of other sources of energy at the local level, they did the same with electricity. A noticeable step was taken in the 1890s, when they grew bigger hydroelectric factories. Second, cities located in rural and poorer *cantons*, which were not able to implement the same model as the richest cities, turned to another model. They delegated the production and distribution of electricity to *cantons* and private companies. Both were associated through the model of *Unternehmergeschäft* (Hertner, 1987), namely ad hoc financial companies or holdings supported by banks to promote the electrification of a territory (Segreto, 1992). All in all, the development of electricity in Switzerland is related to what Pasquier (1998) calls the "Swissification" of electric infrastructures, meaning that all these previous factors helped to build the national model suiting the domestic characteristics (geographic, economic, political). Consequently, the current Swiss electricity system, which inherited from this, is currently almost decarbonised, which explains the strongly low carbon intensity of Switzerland compared to other IEA members (International Energy Agency, 2019). Since 1950 the electricity demand has multiplied six times in Switzerland (Swiss Association for Water Management, 2018). According to the World Nuclear Association (WNA, 2019), electricity consumption in Switzerland grew at around 2% per year from 1980 to 2000, but since then it has declined by approximately 5% in line with government policy. In 2015 electricity generation was 67.9 TWh, but this dropped to 63.3 TWh in 2016 (Britsh Petroleum Statistical Review (BPSR), 2018). Because of its central location within Europe, Switzerland is a transit country. According to the technical report Swissgrid (Swissgrid, 2015), in 2014 around 25 TWh (out of 78 TWh in total) of the flows on the Swiss transmission grid were caused by transit flows between neighbouring countries, mainly from the north down to Italy.

Fig. 3: Electricity production by source in Switzerland, 1960–2015



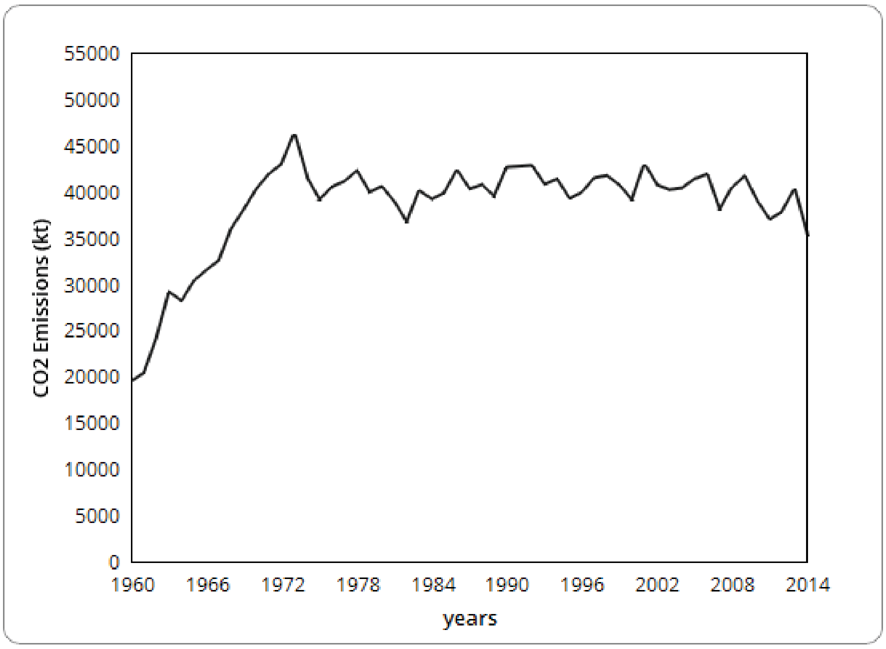
Source: constructed by the authors. Data were taken from the World Development Indicators (WDI, 2019).

v) CO_2 emissions

According to the International Energy Agency (2019), nuclear power has historically been one of the largest contributors of carbon-free electricity globally. Its potential to contribute to power sector decarbonisation is significant. As shown in *Fig.4*, even though the Swiss experienced a strong increase in CO_2 emissions during 1960–1990, CO_2 emissions decreased from 42,610 kt in 1990 to 38,994 kt in 2011. In addition, following the CO_2 Act, Switzerland has committed to reducing its domestic greenhouse gas emissions by 20% by 2020. However, one challenge remains. The transport-sector issue accounted for 44.8% of CO_2 emissions in 2014, which was almost twice as high as in 1979, with 25.2% of CO_2 emissions (World Development Indicators (WDI), 2019). According to the Energy Strategy Report (ESR, 2016), road traffic is the source of 99% of transport emissions. With the highest share of CO_2 emissions in Switzerland, the transport sector is definitely an avoidable issue in the process of reducing carbon dioxide emissions. In addition, 13.6% of CO_2 emissions came from manufacturing industries and construction in 2014 (World Development

Indicators (WDI), 2019). Furthermore, the services and residential sector represented 31% of CO_2 emissions in 2014, which is significant (World Development Indicators (WDI), 2019). At the disaggregated level, the services sector accounted for 4% of greenhouse gas emissions in 2014 (Energy Strategy Report (ESR), 2016). Several efforts are planned for the reduction of CO_2 emissions in the residential sector, which on its own accounted for 17% of Swiss greenhouse gas emissions in 2014, principally as a result of space and water heating. Finally, agriculture accounted for 14% of total greenhouse gas emissions in 2014. Even if the absolute value of Swiss greenhouse gas emissions is still high, at international level and compared to other developed countries, Switzerland is a credible economy in terms of environmental effort. For all these reasons, Switzerland is considered to be the country with the lowest carbon intensity among all IEA members (International Energy Agency (IEA), 2019).

Fig. 4: CO_2 Emissions in Switzerland (kt), 1960–2014



Source: constructed by the authors. Data were taken from World Development Indicators (WDI, 2019).

Given the huge dependence of the Swiss economy on fossil fuel imports, the low-carbon electricity sector, because of both nuclear and hydropower sources, and the insufficient place that is currently occupied by alternative energies such as solar, wind and biomass in electricity generation, Switzerland's current energy mix is unique. However, following the decision of its population to gradually phase out nuclear power through a national referendum in 2017, Switzerland's energy sector is now undergoing a considerable challenge, which corresponds to a deep and historic energy transition.

3. Changes in the Swiss energy structure after 2018

i) The origin: the Fukushima nuclear accident and its cascading reactions at international level

According to Huenteler et al. (2012), on 11 March 2011 a 9.0-magnitude earthquake struck off the coast of Japan's Tohoku region, followed by a tsunami and a nuclear meltdown at the Fukushima Dai-ichi power plant. The accident, and the continued struggle to contain radiation at the 4.7 GW nuclear facilities, plunged the country's electricity sector into crisis. According to Kim et al. (2013), the Fukushima nuclear accident was extraordinary in terms of significant and extensive damage and its negative effect on local and global environments. According to the report by Japan's Atomic Industrial Forum, around 15,000 terabecquerels of caesium-137 were released from reactor 1-3 during this accident, which represents 168.5 times that of the atomic bomb dropped on Hiroshima. Radioactive materials from the Fukushima accident, including iodine-131, caesium-134 and caesium-137, were detected around the world, including in North America and Europe. High levels of radioactive isotopes were also released into the Pacific Ocean. People within a 20-km zone around the Fukushima Dai-ichi nuclear plant had to leave the area, with more than 80,000 people being displaced (International Atomic Energy Agency (IAEA), 2011). The disaster was classified as a Level 7 nuclear accident, the highest level on the International Nuclear Event Scale, equal to that of the Chernobyl nuclear disaster.

Having revealed the vulnerability of the country's power system, the disaster appears to have shifted the fundamental paradigms of the energy policies of several industrialised countries. Many governments changed or redirected their investments in nuclear energy, and the construction of various nuclear power plants was suspended (Ramana, 2011). Even though in the UK policy-makers remained firm in their decision to increase nuclear power generation in the near future, the incident was largely used to reconsider past decisions on planned nuclear power sites (Wittneben, 2012). The Japanese government started an immediate shut-down of its nuclear power plants in order to lead a security and safety survey around its atomic infrastructure. In addition, a comprehensive review of its energy policy was announced and its plans to build additional nuclear reactors were halted. Four days after the disaster, Germany shut down nine of its eighteen operational nuclear power reactors, and announced an acceleration of its "EnergieWende", which consists of a complete phase-out from nuclear energy after 2022 through the use of fossil fuel energy coupled with emerging renewable sources as energy substitutes. Even though the United States government appeared determined to retain nuclear energy as part of its national energy mix, some officials cautioned that the country should learn from the Fukushima nuclear accident (Ehreiser, 2011). In addition, Italy decided to exclude nuclear energy from its future energy mix (Froggatt and Schneider, 2011). Finally, Switzerland agreed to phase out its five power reactors as they reach the end of their life cycles after 2034. According to the World Nuclear Association (WNA, 2019), operating Swiss power reactors are mostly expected to close in 2034 (Beznau I (closure expected in 2030), Beznau II (closure expected in 2031), Mühleberg (closure expected in 2019), Gösgen (closure expected in 2029) and Leibstadt (closure expected in 2034)).

However, explaining this radical change in national energy strategy cannot be separated from the drastic changes in public opinion concerning the nuclear issue created by the Fukushima accident. According to Kim et al. (2013), the nuclear disaster changed public attitudes towards nuclear power in different countries before revising existing nuclear policies. It significantly lowered public acceptance of nuclear energy. If public acceptance of nuclear energy is highly correlated with government's political decision-making, it explains the numerous demonstrations against nuclear power observed around the world, notably in Japan and Switzerland. Consequently, Kim et al. (2013) underline the point that the Swiss, German and Japanese governments also chose to provide a convincing nuclear energy policy, reflecting the change in public acceptance of nuclear energy after the catastrophe. The latter argument is particularly relevant for the Swiss case. The political construction of Switzerland is based on a rare place being accorded to public opinion on global questions. Indeed, it is worth remembering the political organisation of the country, which is influential on environmental and energy choices. Specifically, Switzerland's political functioning rests on the "magic triangle" (Vallet, 2010) built of neutrality, federalism and direct democracy. These three poles are intertwined. First, neutrality ensures that the country is not totally dependent upon other countries and not committed to external political obligations. With respect to energy, this means that the country makes sure its imports do not favour rogue countries or support countries at war, for instance. Second, federalism implies that each political decision should be taken at the local scale first, and only later on cantonal or national levels (Church & Head, 2013). In other words, cities and cantons are the most relevant political scale in Switzerland at which to make decisions. The Swiss Federal Council and the two Parliaments (one being related to the local scale) also exert power over some decisions, but to a lesser extent. Federalism has hampered state interventionist policies in Switzerland (Obinger 1998). Third, direct democracy is associated with referenda and popular initiatives, giving many rights to Swiss people to be consulted on some decisions and even to suggest policies. Regarding the environment generally, this pillar of the Swiss political system means that each strategic choice will have to be ratified by the Swiss people, or taken first at the local scale. For instance, in the canton of Neuchâtel in 2014 the local government was compelled to implement a referendum to validate its decision to install wind turbines.

ii) Changes in energy policy paradigm: the Swiss case

Following the change in public opinion concerning nuclear issues, a new policy approach has emerged in response to the crisis in Switzerland. The Fukushima disaster highlighted the merits of a decentralised and resilient energy supply system for both countries. Electricity generation is called to change radically in the near future in Switzerland: in May 2011 (two months after the nuclear accident of Fukushima) the Swiss Federal Council (the executive power) and the Parliament underlined the possibility of phasing out nuclear energy. After several discussions and a national referendum in 2017, as mentioned in the Introduction a plan called "Energy Strategy 2050" was adopted in 2017 and officially came into being on 1 January 2018. The decision to withdraw from nuclear energy production consists of closing the five power plants currently in operation in Swiss territory between 2019 and 2034. Serious efforts are planned for the development of renewable energies. In addition, an important place is dedicated to the improvement of energy efficiency.[4] At the same time, CO_2 emission reduction targets such as the Kyoto Protocol and the Paris Agreements are being maintained. In all cases, a change in national energy policy would also affect CO_2 emissions, technological innovation, national competitiveness and corporate policies.

In September 2013 the Swiss Federal Office of Energy (SFOE) published the final report of the proposed measures in the context of the "Energy Strategy 2050", which outlines an energy scenario where nuclear energy must be substituted by alternative sources. The aim of Switzerland's energy strategy is to ensure security of the supply, as cheaply as possible, and to favour renewable energy sources in order to respect environmental agreements. Implementing the Energy Strategy 2050 faces difficult challenges, because nuclear power (39.1%) is now the second-most consumed electricity source in Switzerland after hydropower (54.2%) (Bundesamt für Energie (BFE), 2014). Considering that Switzerland has almost reached the maximum of its potential in terms of hydropower capacity (95%), renewables are more likely to be alternative when the nuclear phase-out takes place (Diaz Redondo and Van Vliet, 2015). Consequently, solar and wind power will play an important role in the future Swiss electricity mix, even though currently new renewables account only for 0.9% of electricity production (Bundesamt für Energie (BFE), 2014). However, this does not mean that the lever represented by hydropower in the energy transition would become marginal. Following the final project report, "The Future of Swiss Hydropower" (2019), Swiss hydropower is still considered to be a crucial component of attaining the intended Energy Strategy 2050 targets. Renewable energy sources such as hydropower would continue to play a leading role because alternative renewable energy sources are still not sufficiently significant to ensure this energy transition on their own. The Swiss Confederation even plans to increase average annual hydroelectricity production to 37,400

[4] Energy efficiency is defined as the percentage of total energy input to a machine or equipment that is consumed in useful work and not wasted as useless heat. It is thus considered to be the first fuel of a sustainable global energy system by the International Energy Administration (IEA, 2019).

Gwh in 2035 and 38,600 Gwh in 2050 (Swiss Federal Office of Energy (SFOE), 2018). Finally, the Swiss "Strategy Energy 2050" (or its revised law, called the "New Energy Act", which will come into force on 1 January 2020) can be summarised in three points (Swiss Federal Office of Energy (OFEN), 2018). First, improving the energy efficiency of buildings, transport and industry, and reducing the average per capita energy consumption from –16% in 2020 to –43% in 2035. Second, increasing and promoting the use of renewable energy such as wind, solar, biomass and hydropower in order to meet national demand. And, third, phasing out nuclear energy in the long term, with safety being the main criterion.

On this point, the Federal Office of Energy (OFEN) published a report in 2017 explaining the main concrete implications of this change of the Swiss energy pattern for the new national energy law of 2018. Globally, this project concerns encouraging renewable energies through subvention on solar panels, small hydropower plants and biomass investments. It promotes and guarantees research and investment in geothermal energy and newly considers as a "national issue" the production of electricity from renewable energies, as decided for the protection of the environment a few years ago. Following this change, these two elements will have the same status, and thus the same weight, in the future debate. Finally, an effort is being made to achieve energy efficiency, with an increase in the capital endowment of the instrument of request for the proposal in order to improve investment and research in this area. In addition, a new tax scheme regulation concerning CO_2 emissions from vehicles will be added to the actual law by limiting the oldest and most polluting cars (CO_2 emissions superior to 95g CO_2 /km), as well as a policy of "super-credits" in order to stimulate the choice for less polluting vehicles (CO_2 emissions inferior to 50g CO_2 /km) by consumers. This energy strategy will not avoid the energy consumption and CO_2 emissions of Swiss housing, which seeks to improve the current programme of financial retribution for renovation work and smart building construction. Finally, the nuclear sector is concerned with prohibiting the building of new nuclear power plants and authorisation to deliver electricity to the domestic market, which is only valid as long as the safety of the power-plant infrastructure evaluated by the Federal Nuclear Safety Inspectorate (IFSN) is guaranteed. It is observed that no decree or modification of the current national energy law concerns fossil fuel energy specifically as a substitute to a nuclear energy phase-out in electricity production.

iii) Which energy scenario should support the phasing out of nuclear energy?

Because of the challenge of the substantial modification of the national electric system in Switzerland, relevant articles such as those by Diaz Redondo and Van Vliet (2015) have evaluated the feasibility of the Energy Strategy 2050. This consists of analysing future situations from a variety of viewpoints. The Energy Strategy 2050 proposes two electricity scenarios, which are described in Diaz Redondo and Van Vliet (2015), variants C and C&E, both of which are committed to the high development of renewables. *Variant C&E* gradually eliminates imports of electricity: Switzerland will cover its electricity consumption through domestic generation. Increased production of renewable electricity will ensure this happens, mainly through solar and wind energy. It is planned that renewables will produce 14.3% of electricity in 2035, and 23.7% in 2050. Likewise, the electricity from fossil fuels could reach 24.8% in 2035, and 16.5% in 2050. On the contrary, *variant E* includes imports of electricity. They will significantly increase in 2035 from the current levels, with a return to current levels in 2050. Net imports are currently 13% of the electricity generated in 2014. Variant E set 30% of imports in 2035, and around 13% in 2050. Exports are equal in both variants. Without counting transit, exports currently represent 11% of the electricity generated. In 2035 exports will make up 3.3% of the current electricity generated, and 8.2% in 2050. Solar and wind production will increase, up to 12.9% in 2035, and 26.6% in 2050. In this variant, the electricity from fossil fuels will be lower, in favour of imports, up to 7.6% in 2035, and 6% in 2050. However, the results of the linear optimisation framework (with an intra-annual time resolution of one hour) show that variant C&E of the Energy Strategy 2050 is not possible without expected imports. Although the capacity of solar and wind will increase to 26.7% in 2050, imports of electricity will be needed. In brief, they show the unfeasibility of electricity scenarios with a high share of renewables, where Switzerland is a kind of "autarky" and thus does not import electricity from foreign suppliers. In addition, it will involve choosing an intermediate scenario between variants E and C&E, where both electricity imports and electricity generation from fossil fuels are not relevant either. Indeed, even if the International Energy Agency includes natural gas as a bridging fuel in the transition to renewables for Switzerland, Diaz et al. (2017) investigated the question of whether such use of gas is necessary or cost-effective. Using a cost-optimisation model in the Swiss case, they found that gas delivers little to no cost savings as a bridging fuel in a system that switches to wind and solar. Therefore, they strongly suggest developing renewable energies without using natural gas as a substitute for nuclear energy in electricity generation. Consequently, the final scenario adopted by the Swiss government would appear to be closer to variant E in Diaz Redondo and Van Vliet (2015), for several reasons.

First, this scenario uses the possibility of electricity imports from foreign suppliers, which cannot be overlooked in order to fill the gap left by nuclear power closures (Diaz Redondo & Van Vliet, 2015). Second, this scenario is the most capable in terms of solving a situation where the national electricity demand would be superior to the supply. This is explained by the fact that electricity can only be stored in limited amounts and cannot be disposed of; thus, excess supply is not possible (Abrell, 2017). Because electricity demand and supply need to be balanced in every instance in time, avoiding failures of the electricity system, using electricity imports would be the most relevant solution to face the demand and supply disequilibrium in the electricity market (Abrell, 2017). For instance, in the Swiss case, for a positive shock in electricity demand during the winter season, one can only answer with an increase in electricity supply and also an increase in electricity imports from foreign suppliers. Third, this scenario does not use electricity generation from fossil fuels such as natural gas sources, which is relevant because this fossil source would deliver no cost savings as a bridging fuel (Diaz et al., 2017). To conclude, following the official report from the Federal Office of Energy on the form taken by the new energy law of 2018 (OFEN, 2017), and the empirical studies conducted by Diaz Redondo et al. (2015) and Diaz et al. (2017), the possibility is underlined for Switzerland to pursue its energy transition without electricity generated from fossil fuel and by promoting the development of renewable energy. Given the likely increasing role of renewable supply sources in addressing the challenges facing the energy system, the need to ensure that the supply is available over seasonal and daily time periods may emerge as an increasingly significant issue (Kannan & Turton, 2016). Consequently, importing electricity from foreign suppliers appears to be an unavoidable determinant of success in this national project. Following Abrell (2017), because electricity can only be transported from producers to consumers using the electricity grid, promoting electricity imports needs to achieve connection among national grids. Therefore, the success of the Swiss energy transition depends on the feasibility of these electricity imports from foreign suppliers: international energy agreements are the key to answering this challenge.

iv) The EU–Switzerland energy agreement: project and issues

According to the Swiss Federal Office of Energy (SFOE, 2019), Switzerland's electricity market and infrastructure have been closely interlinked with those of its neighbouring countries for several years. For instance, the first connection between the European and Swiss electricity grid was made more than fifty years ago: at the time, "the star of Laufenburg" was the first to connect the European high-voltage grids (Pauli, 2018). In the wake of the bilateral agreements signed in 1999 and 2004 (Vallet, 2012), Switzerland has been negotiating with the EU on a bilateral agreement in the electricity sector since 2007. However, this integration into the European electricity market had still not been achieved when negotiations were extended in 2010. Finally, a new electricity agreement, which had been fully negotiated by 2014, was not adopted after the EU stopped negotiations for political reasons (Pauli, 2018).

However, because of the Energy Strategy 2050, more and more electricity imports into Switzerland will become necessary (Pauli, 2018). This is referred to as the "electricity gap", which it is said will arise around 2020. However, by 2015 Switzerland was only in a position to produce significant electricity surpluses in three summer months, and it was hardly able to achieve a reasonable balance of electricity imports and exports over the year (Pauli, 2018). This situation will worsen if Swiss nuclear power plants are shut down as planned and the expansion of new renewable energies continues as slowly as today. As Pauli (2018) explained, Federal Councillor Doris Leuthard, Head of the Federal Department of the Environment, Transport, Energy and Communications, does not see this electricity agreement as a problem. She wants to secure Switzerland's power supply with electricity from abroad. Logically, the Electricity Agreement is "mandatory" for her. It can be summarised as follows: "The Idea of self-sufficiency and public service has no place in the numerous studies and experts opinions" (Pauli, 2018, p. 2). However, in situations of widespread electricity shortages, each country will use its own power with priority, and Swiss electricity imports from abroad will no longer be ensured (Pauli, 2018). According to the "Energiewende", the abundant electricity generation capacity available today in Germany will be significantly reduced in the future because of its decision to phase out nuclear energy generation by 2022. In addition, existing coal-fired power plants will perhaps not generate enough energy for both domestic and foreign demand in the future.

Because Switzerland can no longer fully rely on its own electricity production, several initiatives are again being tried to promote a new EU–Switzerland agreement. For instance, the International Energy Agency (IEA) recommended in 2018 pushing for a positive outcome in negotiations with the European Union (EU) on the planned electricity agreement between Switzerland and the European Union (International Energy Agency (IEA), 2018). Even though the EU–Switzerland agreement of 2014 was put on hold by European negotiators in the same year, a provisional agreement was proposed in 2015 on the basis of the fully negotiated electricity agreement of 2014 (Pauli, 2018). Because the electricity agreement with the European Union (EU) is intended to regulate all the requirements for an open market in Switzerland, its official ratification would establish a legal framework for Switzerland's participation in the European electricity market and thus favour Swiss electricity imports from foreign suppliers in the European Union. Consequently, Switzerland plans to link to the energy markets of the European states through "Market Coupling" and become a member of the large internal energy market. This agreement would enable Switzerland to promote its role as a "green" European electricity hub, but also to secure its electricity imports because of its fluctuating national electricity generation. In addition, it would facilitate the use of energy from renewable sources in Europe because it would result in the mutual recognition of certificates of origin for electricity from water, wind and sun. It would thus allow Switzerland to position itself in the area of renewable energy throughout Europe. Moreover, this energy agreement would benefit more than just Switzerland. First, Switzerland is located in the centre of Europe and is therefore predestined as a transit state, especially in the north–south direction, because Germany and Northern Italy have an important interest in building electricity trading routes through Switzerland. Second, important potential electric generation plants are located in Germany and France for storing the volatile electricity production from renewables in Switzerland, but this is not reciprocal. Contrary to popular opinion, Switzerland does not have enough pumped storage plants and reservoirs to become interesting for the European Union (EU) as a reserve electricity supplier (Pauli, 2018). Switzerland's storage capacities are relatively small considering the important quantities of electricity demand in the European Union (EU) and the necessity for this country to ensure its domestic energy demand. Electricity imports through an energy agreement between the European Union and Switzerland would be a central factor in coping with the integration of renewable energies; and this would have an impact on both Switzerland and the European Union.

According to Pauli (2018), the content of the electricity agreement as it was negotiated is not public. However, it can be expected to adopt the objectives listed in the EU's Third Internal Market Package. It corresponds to ambitious environmental targets to be achieved in 2020 such as: 20% share of renewable energies, 20% reduction in CO_2 emissions (1990 basis) and a 20% reduction in energy consumption (1990 basis). They will be revised upwards for Switzerland because of the time-shift in the adoption of the EU–Switzerland agreement, but also because of the latter's good starting position in terms of CO_2 emissions and share of renewables in total energy consumption. Fully open markets will also be included as a key objective (Pauli, 2018). The consequences of this agreement for the Swiss electricity sector are important. Local utilities owned by the municipalities and cantons would be privatised. All activities in the field of electricity supply in Switzerland would have to be put out to international tender. Because access to European regulatory bodies is still partially denied for Switzerland, in return it would be able to sit at the table in all European regulatory bodies on the subject of electricity and at least find out what is planned in detail (Pauli, 2018).

v) The missing transport sector: the last challenge in CO2 reduction

When it comes to transport activities, Switzerland is also a special case, with a well-developed public transport infrastructure offering a very high-quality service.[5] It is important to note that large parts of the country are mountainous regions, where there is no real alternative to private cars. Even though the "Energy Strategy 2050" corresponds to a deep energy transition, it concerns the electricity sector and notably the substitution of renewable energy sources for nuclear power. It does not concern the question of oil imported from foreign suppliers, which is a burning issue, notably concerning CO_2 emissions. In fact, the electrification of the transport sector plays a minor, or non-existent, role in the Energy Strategy 2050. However, according to the Swiss Federal Office of Energy (SFOE, 2019), the fuel for road transport increased from 19,070 TJ to 290,100 TJ over the period 1950–2017, multiplying 15 times. In addition, the transport sector represented 36% of total energy consumption and 56% of total oil consumption in 2015 (World Development Indicators (WDI), 2019), which underlines the issue of greenhouse gas emissions, which are a direct consequence of the important

5 Among the bilateral agreements signed entered into force in 1999, was the issue of rail transportation for trucks crossing Switzerland. Switzerland has a true competitive advantage in this field.

need for petroleum products by this sector. This is explained by the fact that Switzerland has an important rate of motorisation, with 543 vehicles per 1,000 inhabitants, which is higher than the European rate of 507 vehicles per 1,000 inhabitants in 2016 (Statistical Report "Mobility and Transport", Federal Statistical Office, 2018). For this reason, the Federal Council is envisaging more vigorous measures to reduce oil consumption and plans to invest in the infrastructure of common transport such as the international CEVA train-line project between Cornavin (Switzerland) and Annemasse (France). Therefore, given the huge dependence of Switzerland on fossil fuel imports for its transport sector, the nuclear phase-out would not improve national energy security and independence concerning the oil supply. In addition, in 2017 Switzerland ratified the Paris Agreement (Federal Office for the Environment (FOEN), 2019), committing to supporting the two-degree target (compared to the pre-industrial period) fixed by the United Nations Framework Convention on Climate Change with its resources (Climate Change Convention (UNFCCC), 2017). In the same year, the transport sector accounted for 44.8% of total CO_2 emissions. Consequently, this sector remains a serious obstacle in the simultaneity process of nuclear phase-out, energy security and independence improvement and CO_2 emission reduction. Moreover, the neglect of the transport sector in the Energy Strategy 2050 will restrict a successful energy transition in Switzerland.

This section highlights four important points. First, the decision to phase out nuclear energy in Switzerland has been followed by a national plan ("Energy Strategy 2050") and applied through decrees, which came into force in the new energy law on 1 January 2018. Second, considering the current mitigation efforts to reduce CO_2 emissions, notably through the Kyoto Protocol (adopted in 2002), Switzerland is choosing a strategic approach without substituting fossil fuel for nuclear power in the electricity generation process (such as Germany). Third, the Federal Council adopted a scenario that consists of filling the gap left by nuclear-power-plant shut-downs through the significant development of alternative and renewable energy sources such as solar, wind, biomass and hydropower on domestic territory in the long term. Consequently, the Swiss government will need large electricity imports from its neighbours and foreign suppliers. Using energy imports will allow Switzerland to answer its domestic energy demand, to fill the gap left by seasonal fluctuations of renewable energy generation, and thus to achieve the transition of its energy pattern. Fourth, the Swiss–EU electricity agreement would allow Switzerland to link to the energy markets of European states and thus benefit electricity imports as a member of a large internal energy market. It therefore appears necessary to observe the effect of this global reform on its energy security and independence. Finally, one missing element of Swiss global energy reform is the transport sector. Because it still concentrates largely on fossil fuel consumption and CO_2 emissions, it appears to be the main aspect of this deep transition.

4. The "Energy Strategy 2050" as both an advantage and a constraint to national energy's security and independence: improving energy sovereignty as a compromise between security and independence issues

i) Definitions

(1) Energy security

First, as related by Yergin (2006), the notion of energy security originates from Winston Churchill's decision to convert the British Navy from coal power to fuel oil before World War I. Even though this decision was taken with a view to becoming dependent on foreign oil sources, it was also taken for safety and certainty reasons because of the large variety of oil suppliers compared to the small number of coal suppliers on an international scale. It was summarised in 2005 by Lord Brown as follows: "Winston Churchill once said that security in oil came from a diversity of supply. That was right in 1915, and it is right now" (29 November 2005, speech by Lord Brown, Group Chief Executive of British Petroleum, at the Brookings Institution, Washington, DC). According to the Annual Threat Assessment of the Director of National Intelligence for the Senate Select Committee on Intelligence (p. 41, McConnell, 2008), access to stable and affordably priced energy supplies has long been a critical element of national energy security. On this point the International Energy Agency (IEA) extends the initial energy security definition by Churchill to refer to it as "the uninterrupted physical availability at a price which is affordable, while respecting environment concerns" (IEA, 2010). According to Hughes (2012), this definition can be parsed into three indicators (or dimensions) of energy security: availability ("the uninterrupted physical availability"); affordability ("a price which is affordable); and acceptability ("respecting environment concerns). The International Energy Agency (IEA, 2019) distinguishes two dimensions of energy security: short-term and long-term energy security. Short-term energy security focuses on the ability of the energy system to react quickly to sudden changes in the supply–demand balance. On the contrary, long-term energy security mainly deals with timely investments to supply energy in line with economic developments and sustainable environmental needs. A lack of energy security is thus linked to the negative economic and social impacts of either the physical unavailability of energy or prices that are not competitive or are too volatile. Improving energy security corresponds, finally, to the strategy to ensure the procurement of energy, but it does not necessarily rely on autarky. This could be done through domestic production but also through secured imports from foreign suppliers and safety energy agreements. In the case of Switzerland, this could be reached through bilateral agreements with the EU, for instance, which ensure the stability of contracts that is necessary for energy security.

(2) Energy independence

Second, the term energy independence was coined in 1974 after the Arab oil embargo. It was defined as domestic access to a variety of energy resources, which provide an alternative to imported energy resources. Reciprocally, according to Eurostat (2018), energy dependency shows the extent to which an economy relies on imports to meet its energy needs. The indicator is calculated as net imports divided by the sum of gross inland energy consumption. Consequently, where energy security requires a large variety of foreign energy suppliers per energy type, energy independence requires a variety of energy resources, notably alternative and renewable resources, which are directly exploited or generated on domestic territory. Improving energy independence corresponds, finally, to being able not to rely on other countries to produce and consume energy (raw materials, energy mix, technical skills, currency exchanges (invoice currency).

ii) Consequences of "Energy Strategy 2050" for Swiss energy security and independence

(1) "Energy Strategy 2050" and its effects on Swiss energy security

The decision to phase out nuclear energy (long-term energy security) faces several underlining challenges, notably the unavoidable use of electricity imports from foreign suppliers (short-term energy security) to ensure this energy transition. As explained before, following the scenario of the transition described by the Federal Office of Energy on the form taken by the new energy law of 2018 (OFEN, 2017), this change of energy pattern will not imply a substitution of electricity from fossil fuels to electricity from nuclear energy. One would think that energy security refers to the capacity of a country not to use foreign suppliers for its energy needs (energy independence). On the contrary, energy security refers to the capacity of a country to use a large number of foreign suppliers in order to secure its energy supply. Consequently, the development of alternative and renewable energy sources, combined with the use of electricity imports from foreign suppliers, would necessarily impact Swiss energy security. According to the aforementioned definition of energy security given by Winston Churchill in 1915, and related by Yergin (2006), the new energy strategy pursued by Switzerland would improve its energy security. According to its new electricity supply (foreign combined with national electricity generation), a larger share of the electricity consumed domestically would come from foreign suppliers. It would have the advantage of both answering the fluctuation in domestic demand and filling the gap left by renewable electricity generation over the years because both change according to the seasons.

When facing these challenges, the project of the EU–Switzerland energy agreement seems to become a central issue. The potential ratification of this partnership would seek to allow Switzerland to participate in the European electricity market and thus to promote electricity imports from foreign suppliers. Therefore, becoming a member of the large internal energy market through bilateral agreements with the EU would necessarily improve its national energy security while still allowing Switzerland not to become a full member of the EU, which is its long-term strategic position (Rossi & Vallet, 2017). The latter argument is supported by the diversity of electricity suppliers in the European Union, but also by the safety of the connected grids and the stability of trade partnerships with such European countries. Thanks to the strategic geographic localisation of Switzerland, it appears to be the missing piece of the puzzle in achieving a unique large electricity market aimed at simultaneously connecting the North of Italy and Austria to Germany and France. Through an EU–Switzerland agreement, Germany and France represent a strong opportunity for Switzerland to reach important electricity suppliers. As an instrument for the development of electricity imports, and following the definition given by Winston Churchill (1915), the project of the EU–Switzerland energy agreement would also benefit Swiss energy security because of the diversity and safety of foreign electricity suppliers.

(2) Maintaining the Swiss energy independence : another challenge caused by the nuclear phase-out :

Renewable energies have the advantage of being available locally and in infinite quantities in the long term. In addition, they are in line with the mitigation efforts promoted by the Kyoto Protocol to reduce CO_2 emissions. Therefore, promoting renewable energies to phase out nuclear generation will be directly observed through the radical reduction of uranium fuel imports from foreign suppliers. Because Switzerland has for a long time been a net importer of natural uranium, its dependence upon a small number of foreign suppliers has increased considerably: just 15 countries shipped 99.9799% of global natural uranium exports in 2018 (World's Top Exports (WTE), 2019). Consequently, according to the definition of energy independence mentioned above, the new energy strategy pursued by Switzerland would improve its energy independence. However, one limitation for a small open economy like Switzerland is that it could be difficult to fulfil the objective of complete independence. Switzerland has built its economy on exporting goods and services from advanced technology sectors. And if a country imports less, it will maybe also export less, entailing macroeconomic disequilibria. Another point is that even if using foreign suppliers to import electricity reduced Swiss energy independence, it would necessarily improve its energy security. These notions of energy security and independence must thus be considered as related and interconnected.

One solution to limit the reduction of Swiss energy independence is the improvement of energy efficiency, which begun to be improved a few years ago in Switzerland. According to the International Energy Agency (IEA, 2018), much effort is currently being made in this direction. For instance, national energy consumption in 2016 in Switzerland remained at the same level as in 2000, despite a 15% population growth and an economy that was 30% larger. It is also observable through the decrease in total energy use per capita from 3,304 to 2,960 kg of oil equivalent per capita between 2013 and 2015 (World Development Indicators (WDI), 2019). Therefore, improving energy efficiency is one of the three main objectives of the "New Energy Act" (2020), the actualised version of the "New Energy Strategy" (2018). According to Patterson (1996), energy efficiency is a generic term, and there is no one unequivocal quantitative measure of energy efficiency. Instead, one must rely on a series of indicators to quantify changes in energy efficiency. In general, energy efficiency refers to using less energy to produce the same amount of services or useful output. For instance, in the industrial sector, energy efficiency can be measured by the amount of energy required to produce a tonne of product. Hence, energy efficiency in the electricity sector in Switzerland can be defined by the following simple ratio: the useful output of a process divided by the electricity input into this process. Following the "Energy Strategy 2050", the improvement of energy efficiency in electricity generation concerns two main sectors: the domestic (building, cooking, heating) and the industrial (machinery) sectors. Consequently, if the electricity used in those sectors to produce the same amount and quality of products and services decreased across time, this would reduce electricity imports from foreign suppliers. The latter argument is robust considering that electricity is hardly storable (unlike natural gas or oil). Following Abrell (2017), because electricity cannot be disposed of (excess supply is not possible), improving energy efficiency in Switzerland would allow it to reduce its electricity imports from foreign suppliers because of the decrease in its national electricity consumption.

iii) What about sovereignty?

(1) Definitions and opportunities created by the Energy Strategy 2050 for Switzerland to preserve sovereignty

The concept of sovereignty has two dimensions: internal and external. Concerning the preservation of external sovereignty, one basic postulate in the case of Switzerland is that the country is dependent on overseas markets in order to exist. This is particularly the case regarding the EU (Guillaumin & Vallet, 2012), whereby Switzerland must respect its trade agreements and thus import from foreign countries (notably raw materials) in order to ensure its own export opportunities of high-value-added goods to these foreign markets. Regarding the preservation of internal sovereignty, the case of Switzerland is notable. To the best of our best knowledge, Switzerland has always been sovereign on its territory through multiple and recurrent choices not to enter the European Union, not to adopt a common currency and, finally, not to take a position on international conflicts between European countries over the past century. Concerning energy sovereignty, it can be considered as the ability of a political community to have the authority to control, regulate and manage its own energy. This can be seen as the right of conscious individuals, communities and peoples to make their own decisions about energy generation, distribution and consumption, in a way that is appropriate within their ecological, social, economic and cultural circumstances. It acts nowadays as a slogan for organisations and movements to reclaim the right to decide upon energy, understood as a natural commons and basis of life for all. It also refers to the plurality of systemic alternatives in a way that challenges the dominant energy paradigm controlled by centralised powers. However, in our view, considering the Swiss case, such a definition of sovereignty should be rethought. Gathering two features – internal and external – sovereignty rests on three keystones, as follows:

(1) Institutional: Institutions must ensure that a country as a whole is able to access energy, for the needs of its entire population. This requires both an internal, stable political system and external connections with other countries in order to ensure the stability of economic contracts coping with energy. Regarding the internal dimension, Switzerland rests on a stable political system enabling people to make their own democratic choice regarding energy: since the local scale is the most important one in Switzerland, and given that the country is hyper-globalised, the federal state is less powerful in comparison to others in reference to "Rodrik's trilemma" (Rodrik, 2011). Therefore, such a system respects people's political sovereignty first. Regarding external connections, such a feature of energy sovereignty indicates that a country may use imports if the latter provide secure access to energy. Because maintaining trade relationships with neighbouring countries appears mandatory for a small open economy like Switzerland, and since self-sufficiency is impossible in all domains, sovereignty does not appear to be inconsistent with dependence, on the condition that such dependence is secured. In the Swiss case, stabilising its relationship with the EU through bilateral agreements on energy access is of the utmost importance, particularly with the abandonment of domestic nuclear energy production.

(2) Industrial: Switzerland must be able to favour the emergence of new domestic industrial actors in the domain of renewable energy in order to replace some energy sources. This means being able to increase the number of domestic companies associated with renewable energy. Consequently, its capacity to rely on national leaders in the production and development of growing renewable energy sources (such as wind, solar and biomass) would allow Switzerland to bring out new high-tech energy sectors with high-qualified workers and advanced technologies. The aim is to secure the national market, but also to be able to gain market shares abroad in the future. Likewise, another objective is to control the technologies associated with the rise of new industries in order to exploit them. Given the Kyoto Protocol and the Paris Agreements, ratified in 2003 and 2017 respectively, mitigation efforts will be demanded in the future to industrialised countries in order to reduce CO_2 emissions. Considering the structural break caused by the Fukushima nuclear accident in the nuclear energy policy of several European countries (such as Germany and Belgium), the decision for developed

countries to phase out nuclear energy will be increasingly frequent. In addition, this change of energy policy pattern would be coupled with a growing place dedicated to renewable energy sources in electricity generation. According to these elements, important demand will emerge in developed countries (notably in Europe) concerning the construction of renewable energy infrastructure such as important areas dedicated to wind turbines, the development of photovoltaic panels and the construction of biomass power plants directly connected to the national electricity grid. Consequently, Switzerland will have an interest in creating technological and competitive leaders in this sector, which would first be able to meet its domestic needs and second to answer neighbouring demands in renewable energy infrastructure. The connections created between the industry and the financial/banking sectors (through specific financial products and banking services, financial markets dedicated to fundraising, support from the national bank and possible green bonds or sovereign green fund) would really help the industrial sector in this process. In addition, the place dedicated to human capital formation and skills transmissions, specific to the development of new, important renewable energy sectors, is not excluded in this deep transition. Given the successful industrial tradition in Switzerland, this industrial dimension leads to positive forecasting with respect to the ability of the Swiss industry to ease the emergence of newcomers. As mentioned before, preserving Swiss sovereignty relies on an industrial dimension that corresponds to the development of domestic sectors specialising in renewable energy sources. This would be an opportunity to create a standard that would be deemed valuable by foreign trade partners in the future. The catchphrase "the one who produces a standard produces a market" will thus appear increasingly relevant. In that respect, government policies are of the utmost importance in terms of offering the right incentives to economic agents to produce or consume new products through specific tax or subsidy (fiscal) policies.

(3) Monetary and financial: though often underestimated by the literature, the issue of money is key when dealing with the environment, including energy (Svartzman et al., 2019). Indeed, dealing with energy sovereignty is associated with several important dimensions, as follows:

- First, the choice of invoicing currency for energy products (including raw materials): a country that is able to invoice energy products in its own currency relies less on strict macroeconomic and monetary regimes, such as currency reserves. In that sense, Grassman's law states, for instance, that exports are mostly invoiced in the exporter country's currency: "Formally speaking, it is the seller who takes the initiative and decides what the invoice currency is to be. The seller calculates and fixes prices, he submits a tender and sends the purchaser an invoice" (Grassman, 1972, p. 77). Likewise, in the case of the dominance of an international currency, a country may be faced with necessary indebtedness in this currency, leading to the "original sin" (Eichengreen et al., 2002) that threatens its sovereignty.
- Second, the terms of trade: following the previous remark, when trading energy products, a country

is likely to be subject to exchange rate fluctuations jeopardising its sovereignty through disturbances in macroeconomic policies. Stable macroeconomic policies are useful to provide incentives to investors to invest in a currency (Walter, 2006) and then to stabilise exchange rate movements. This argument goes hand in hand with the confidence in the policies implemented by the central bank.

- Three, banking and financial supply: energy production requires banking support and large, deep and liquid financial markets in order to provide funds but also to manage risks (Prasad, 2014). Such a factor is key to increasing confidence in the domestic currency, particularly because it is connected to large international financial markets (Rhee & Sumulong, 2013).

At first sight, this country has burdens: even though *Table 1* shows that Switzerland is one of the leading exporter countries in the world, it is not a large country, which means that it is not able to invoice all its trade in its own currency. However, Switzerland offsets these weaknesses through several key factors. First, its currency tends to appreciate in the long term towards the main international currencies, which increases the Swiss terms of trade (Vallet, 2016). Second, it can rely on a large and stable financial and banking sector, accounting for 15% of GDP. Switzerland rests on leading financial markets for energy product trading, for example, in Geneva. This strengthens Switzerland's position on the external or strategic markets. Likewise, it is able to offer specific financial products dedicated to the management of assets of that kind (AEESuisse, 2016).

Table 1: Share of invoice currencies according to Swiss exports and imports (2012–2014)

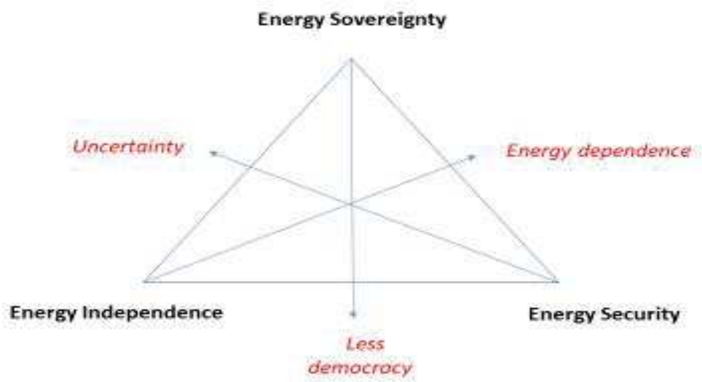
Currencies	Exports			Imports		
	Share in percent			Share in percent		
	2012	2013	2014	2012	2013	2014
Euro	30.6	36.0	35.9	55.3	54.5	54.9
Swiss franc	42.0	34.6	33.7	32.2	32.1	31.6
US Dollar	15.3	16.7	17.8	9.5	10.3	10.6
Other European currencies (GBP, DKK,…)	2.8	2.6	2.6	1.1	1.2	1.2
Other currencies	9.3	10.1	9.9	1.9	2.0	2.2

Source : constructed by the authors with data from Department Fédéral des Finances, 2015.

2) Energy Strategy 2050: preserving Swiss sovereignty as a compromise between energy security and energy independence objectives

Fig. 4 illustrates the "trilemma", with the three sides of the triangle representing the trilemma's three energy goals in the case of Switzerland. According to the Energy Strategy 2050 and its deep energy transition, a key prediction of this triangle model is the impossibility of accomplishing these three policy goals simultaneously for Switzerland. If Switzerland focuses on energy security and sovereignty, it renounces energy independence in order to import electricity from foreign suppliers through international agreements. If Switzerland favours energy independence and sovereignty, it cannot rely on electricity imports to ensure its nuclear phase-out; it can only rely on domestic renewable energy sources that will negatively impact its energy security through uncertainty in its global energy supply. If Switzerland focused on energy independence and security, it would diminish its sovereignty by reducing the range of choices for its population in terms of energy, thus affecting democracy. Consequently, our reflection leads us to the following position: the real challenge created by the nuclear phase-out in Switzerland may not be about becoming independent but rather securing its energy supply and, above all, as has always been the case, preserving its sovereignty. Preserving its sovereignty corresponds to a process that involves securing institutional, industrial and monetary and financial keystones for Switzerland. For this reason, preserving its sovereignty has more meaning than improving it. Although it will certainly continue to import raw materials in the future, it is well armed to be sovereign with respect to the keystones and corresponding energy strategies that were previously identified.

Fig. 5: The Swiss energy trilemma



Source: constructed by the authors.

5. Conclusion and policy recommendations

On the energy issue, as well as other dimensions (trade, competitiveness), Switzerland represents a unique and tremendously interesting case. Electricity generation in Switzerland came mainly from hydropower and nuclear energy, with a corresponding share of 57.9% and 32% in 2015, respectively

(World Development Indicators (WDI), 2019). Consequently, the electricity sector is almost decarbonised, which is why Switzerland is considered to be the lowest-carbon-intensive country of all IEA members (International Energy Agency (IEA), 2019). However, for most of its history, Switzerland has relied on imported fossil fuels, which still represented half of its total energy consumption in 2015 (World Development Indicators, 2019). This has tremendous consequences for its aggregate CO_2 emissions, mainly attributed to the transport sector, which was responsible for more than half of total oil consumption in 2015 (World Development Indicators (WDI), 2019).

The Fukushima nuclear accident in 2011 initiated a structural break in the energy policy of several industrialised countries, such as Germany and Belgium, but also Switzerland. After a national referendum Switzerland decided to phase out nuclear power in 2034 through the "Energy Strategy 2050", a national plan that aims both to cease nuclear energy dependence and to develop renewable and alternative energy sources in the territory in the long term. However, unlike Germany, which decided to accelerate its nuclear phase-out by 2022 through substituting natural gas and coal for nuclear fuel, Switzerland chose a less environmentally harmful but more risky strategy. Indeed, it decided to follow a unique energy policy strategy consisting of limiting the place dedicated to fossil fuel sources and choosing to develop massively renewable energy sources such as wind, solar and biomass in order to fill the gap created by its progressive nuclear phase-out. The main concrete reforms corresponding to this change of national energy pattern are explained in the new national energy law of 2018 in the report from the Federal Office of Energy (OFEN), published in 2017.

"The national issue" is newly dedicated to the production of electricity from renewable energies; subvention on solar panels, small hydropower plants and biomass investments has been significantly increased; investment in research in the energy efficiency area, notably smart building construction, has been unfrozen; a direct tax scheme regulation concerning CO_2 emissions from vehicles has been adopted; and "super-credits" dedicated to low-emission vehicles have been promoted. However, the simulations of several researchers concluded on the necessity to rely on electricity imports from foreign suppliers because renewable energies are still not significant enough in terms of total electricity generation to completely replace the loss in nuclear power. Therefore, energy agreements, such as the EU–Switzerland electricity bilateral agreement – which is still in negotiation – underline the heated debate in which Switzerland would be linked to the energy markets of European countries and thus benefit from electricity imports (mainly from France and Germany, as a members of the large internal energy market). Finally, one missing element of the "Energy Strategy 2050" is the transport sector. Because the reform does not contain strong changes in energy sources for this sector and because it still concentrates largely on fossil fuel consumption and CO_2 emissions, it appears to be the main aspect of this deep transition.

However, the main issue for Switzerland is political: How should it conciliate energy security, independence and sovereignty patterns while preserving the keystones of its "magic triangle" (Vallet, 2010), which has enabled the country to exist since its creation in 1848? Indeed, changes in the Swiss energy policy will affect its energy security, independence and sovereignty patterns, according to the strict definitions mentioned previously in the article. It can be represented as a "trilemma", where a key prediction of this triangle model is the impossibility of accomplishing these three policy goals simultaneously for Switzerland. On the one hand, if Switzerland focused on energy independence and sovereignty, this would have negative effects on its energy security. On the other hand, if Switzerland focused on energy security and sovereignty, it would renounce its energy independence. Finally, if Switzerland focused on energy independence and security, it would damage its sovereignty by reducing the range of choices of its population in terms of energy, thus affecting democracy. As a strategic response, preserving Swiss sovereignty seems to be a compromise between promoting the security of its energy supply and limiting its energy dependence on foreign suppliers. The real challenge created by the nuclear phase-out in Switzerland may not be becoming energy-independent, because this deep transition necessitates important electricity imports, but rather answering its growing electricity demand in the future and securing its energy supply, which is currently experiencing historic changes to a more renewable energy pattern in the long term. Above all, however, as has always been the case, this challenge consists of preserving Swiss sovereignty, which corresponds to a process that entails securing institutional, industrial and monetary and financial keystones for Switzerland. From the onset of its history, Switzerland has always been on a double-edged sword but able to transform its main weaknesses into strengths.

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