Bachelor's thesis at the Lucerne School of Engineering and Architecture

Title	**Energy Self-Sufficient Switzerland by 2050**
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Bachelor's degree program	**Bachelor in Energy Systems Engineering**
Semester	**fall semester 19**
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Abstract English
The recent threat of Global Warming has spearheaded a revolutionary change in the way the world provides and consumes its energy. Countries all over the world are searching for solutions to minimize their own CO2 emissions and implement sustainable renewable energy. This report attempts to discover if it would be feasible for Switzerland to achieve 100 percent energy self-sufficiency, not just electricity, by 2050 using only renewable sources without the contribution of nuclear or imported energy. Literature research and the Swiss ENERGYScope Calculator tool was used to estimate Switzerland's maximum achievable supply from renewable energy sources: solar PV, wind, hydro, biomass, geothermal and synthetic gas. Estimations were also used to determine a realistic range of minimum and maximum demand efficiencies regarding buildings, mobility, industry and appliances. These efficiencies allow for the determination of the minimum and maximum achievable total final energy consumption leading to the results of five possible scenarios, each comprising of the yearly and seasonal energy consumption, annual cost estimates and CO2 emissions. This information was then used to conclude which of the five scenarios qualify as feasible solutions. These solutions were then further analysed with a SWOT and PESTEL analysis to determine the strengths/weaknesses and internal/external impacts of each potential scenario.

Abstract German
Die jüngste Bedrohung durch die globale Erwärmung hat eine revolutionäre Veränderung in der Art und Weise, wie die Welt ihre Energie liefert und verbraucht, eingeleitet. Länder auf der ganzen Welt suchen nach Lösungen, um ihre eigenen CO2-Emissionen zu minimieren und nachhaltige erneuerbare Energien einzuführen. Dieser Bericht versucht herauszufinden, ob es für die Schweiz möglich wäre, bis 2050 eine 100-prozentige Energieautarkie zu erreichen, nicht nur mit Strom, sondern ausschliesslich mit erneuerbaren Energien, ohne den Beitrag von Kernenergie oder importierter Energie. Mit Hilfe von Literaturrecherchen und dem Swiss ENERGYScope Calculator wurde das maximal erreichbare Angebot der Schweiz aus erneuerbaren Energiequellen abgeschätzt: Photovoltaik, Wind, Wasser, Biomasse, Geothermie und synthetisches Gas. Zudem wurde eine realistische Bandbreite an minimalen und maximalen Nachfrageeffizienzen in den Bereichen Gebäude, Mobilität, Industrie und Geräte ermittelt. Diese Wirkungsgrade ermöglichen die Bestimmung des minimal und maximal erreichbaren Gesamtendenergieverbrauchs und führen zu den Ergebnissen von fünf möglichen Szenarien, die jeweils den jährlichen und saisonalen Energieverbrauch, die jährlichen Kostenschätzungen und die CO2-Emissionen umfassen. Aus diesen Informationen wurde dann geschlussfolgert, welche der fünf Szenarien als machbare Lösungen in Frage kommen. Diese Lösungen wurden dann mit einer SWOT- und PESTEL-Analyse weiter analysiert, um die Stärken/Schwächen und internen/externen Auswirkungen jedes potenziellen Szenarios zu ermitteln.

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Lucerne, Switzerland
January 6th, 2020
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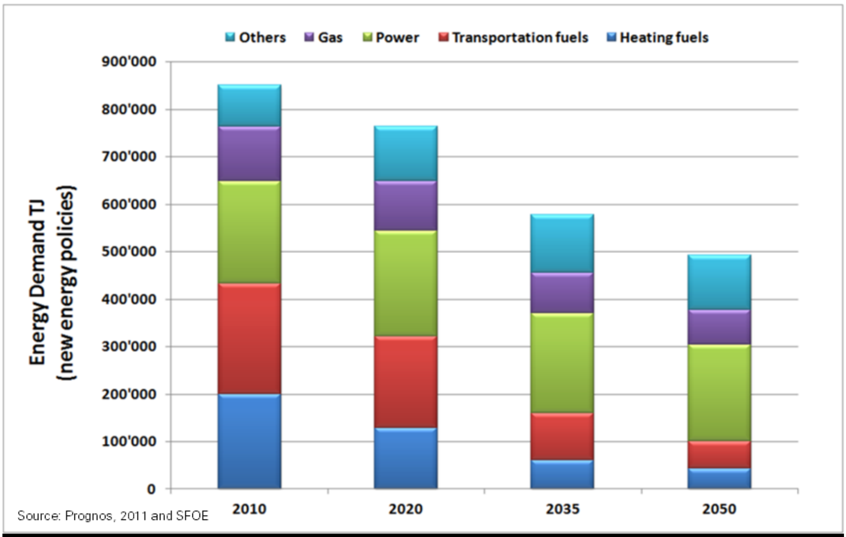
Executive summary

This report attempts to discover if it would be possible for Switzerland to achieve 100% energy self-sufficiency, not just electricity, by 2050 using only 100% renewable sources. It takes into consideration the elimination of nuclear and imported energy. Literature research and the Swiss ENERGYScope Calculator tool was used to estimate Switzerland's maximum achievable supply from renewable energy sources: solar PV, wind, hydro, biomass, geothermal and synthetic gas.

Approximations were also used to determine a realistic range of minimum and maximum demand efficiencies regarding buildings, mobility, industry and appliances. The results consist of different scenarios, each comprising of the yearly and seasonal energy consumption, annual cost estimates and CO2 emissions. This information was then used to conclude which of the scenarios qualify as a feasible solution. These solutions were then further analysed with a SWOT and PESTEL analysis to determine the strengths/weaknesses and internal/external impacts of each potential scenario.

According to multiple sources, the lowest achievable total final energy demand in Switzerland is approximately 139,000 GWh/year (See Figure below) (PROGNOS, 2012) (Katharina Link, et al., 2015). This amount is over 90,000 GWh/year less than the current quantity of consumption.



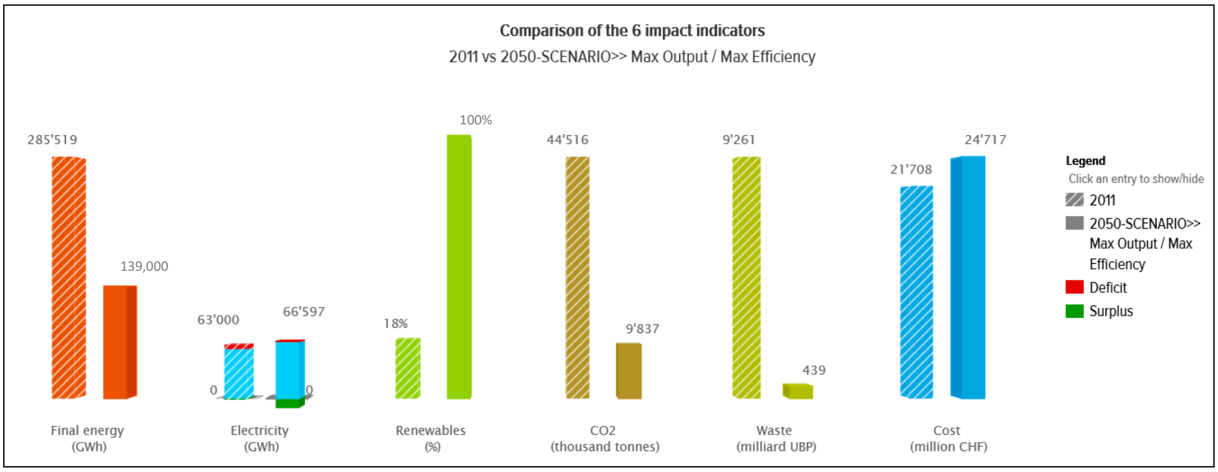
Estimated Energy Demand for Switzerland in 2050
(Katharina Link, et al., 2015) (PROGNOS, 2012)

To meet this demand, five scenarios were developed and analysed regarding the maximum theoretical output of renewable sources available to Switzerland. Of the five scenarios, only Scenario 2 and 5 were considered possible because they could meet the conditions and goals of this report. Scenario 2 consists of combining the maximum possible energy output from renewable sources, with the lowest possible demand (See Figure below). As you can see, this scenario is able to exceed demand with a surplus of 54,500 GWh/year.

Scenario 2		
Minimum Total Final Energy Consumption combined with Maximum Total Renewable Energy Production		
Switz MAX Scenario (GWh)		**%**
Solar PV	67,000	34.63%
Wind	10,000	5.17%
Hydro	37,500	19.38%
Deep Geothermal	0	0.00%
Biomass	27,000	13.95%
Geothermal Heat Pumps	20,000	10.34%
Sub Total	**161,500**	**83.46%**
Synthetic Gas	32,000	16.54%
Total	**193,500**	**100.00%**
Minimum Switz Consumption	139,000	
Surplus	**54,500**	

Scenario 2 Results

It is also able to meet Switzerland's CO2 emission goals of a decrease of 70-85% by 2050 (SwissInfo, 2019). The amount of reduction in this scenario is about 78% compared to 2011. The amount of waste reduction is also significant with a total decrease of about 95% compared to 2011.



Scenario 2 Results Compared to 2011

Scenario 5 is also viable, as it comprises of a combination of Scenario 2's results, with the assumption that technology will improve within the next 30 years. The more technology advances in the future, the easier it will be to implement the results from Scenario 2.

The three scenarios that did not qualify for further analysis were:

- Scenario 1: Application of 100% Global Renewable case study to Switzerland
- Scenario 3: Maximum Renewable Energy Output with Minimum Demand Efficiency (Max Supply / Max Demand)
- Scenario 4: Average Renewable Energy Output with Average Demand Efficiency (Average Supply / Average Demand)

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Abbreviations and Acronyms

bcm	Billion Cubic Meters
BEV’s	Battery Electric Vehicle’s
CFL’s	Compact Fluorescent Lamp’s
CH4	Methane
CO2	Carbon Dioxide
CO2/km	Carbon Dioxide per Kilometer
CRS	Center for Resource Solutions
DHC	District Heating and Cooling
ENSI	Swiss Federal Nuclear Safety Inspectorate
EPFL	Ecole Polytechnique Federale De Lausanne
ETH	Swiss Federal Institute of Technology
EU	European Union
GHG	Green House Gases
GWh	Giga-Watt Hours
HEV’s	Hybrid Electric Vehicle’s
HFC’s	Hydrofluorocarbon’s
IEA	International Energy Agency
kWh/m2	Kilo-Watt Hours per Meters Squared
LED’s	Light-emitting Diode
N2O, NOx	Nitrous Oxides
NDC’s	Nationally Determined Contributions
PEV’s	Plug-in Electric Vehicles
RDF	Refuse-derived Fuel
SCCER-BIOSWEET	Swiss Competence Center for Energy Research-Biomass for Swiss Energy Transition
SES 2050	Swiss Energy Strategy 2050
SF6	Sulfur Hexafluoride
SFOE	Swiss Federal Office of Energy
TFC	Total Final Consumption
tkm	Tons-kilometer
UNFCCC	United Nations Framework Convention on Climate Change
USESC	United States Energy Security Council
WSL	Swiss Federal Institute for Forest, Snow and Landscape Research
ZEV’s	Zero-Emission Vehicle’s
ZWILAG	National Central Interim Storage Facility for Radioactive Waste

1 Introduction

Global warming and its effects are a popular topic amongst today's society. There is an ongoing debate worldwide on whether humans have a direct influence on the overall change in global temperature or if it is just a natural environmental occurrence. According to a report by Berkeley Earth, the Earth's average temperature has been steadily increasing since the industrial revolution and then starts to drastically increase around the same time as the global commercialisation of automotive vehicles (early 1900's) (See **Figure 1** below). The procurement and release of CO2 and CO2 equivalents, via the combustion of fossil fuels and natural gas, are believed to be the main cause of global warming. According to the book, The Green Industrial Revolution, "Carbon dioxide (CO2) makes up the vast majority of greenhouse gas emissions from the sector, but smaller amounts of methane (CH4) and nitrogen oxides (NOx) are also emitted. These gases are released during the combustion of fossil fuels, such as coal, oil, and natural gas, to produce electricity" (Clark II & Cooke, 2015).

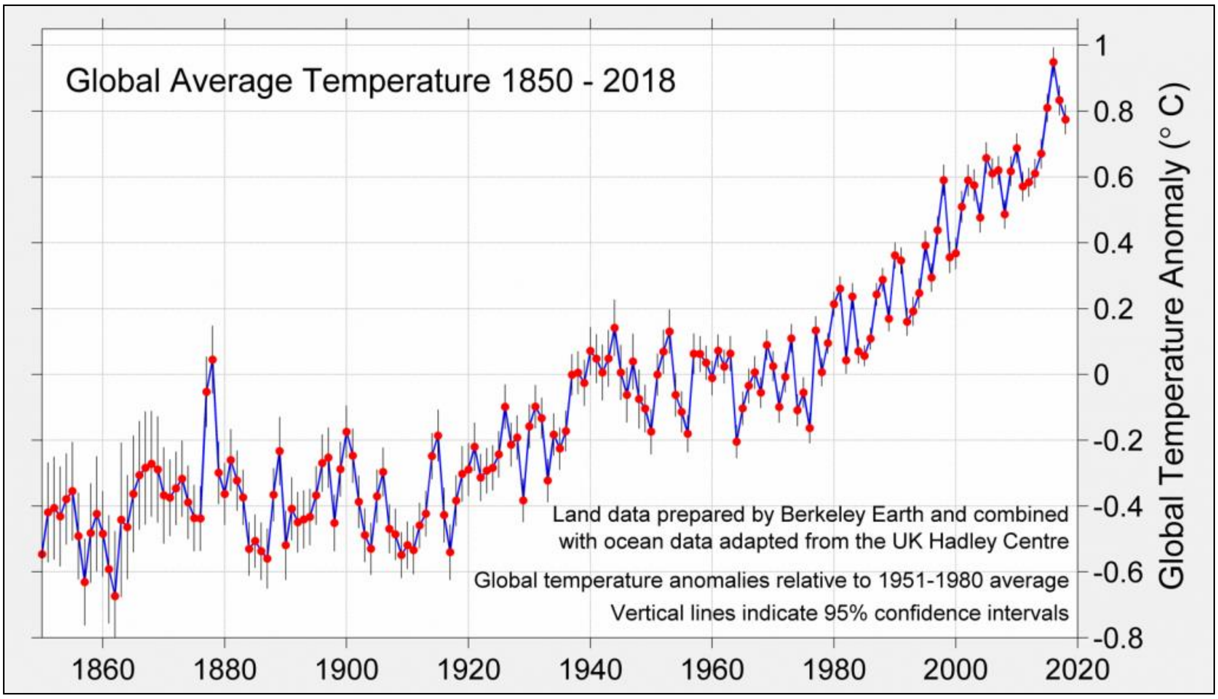

Figure 1: Average Global Temperature Increase from 1880 to 2010
(Berkeley Earth, 2018)

There are also other hazardous effects affecting the environment. According to one source, "Electricity generation is the leading cause of industrial air pollution in the United States. Most of our electricity comes from coal, nuclear, and other non-renewable power plants. Producing energy from these resources takes a severe toll on our environment, polluting our air, land, and water" (BuyCleanEnergy, 2019). There is sufficient evidence from the scientific community to support the damage done by harvesting and combusting fossil fuels. Whether this damage is 100 % manmade or not, there is a responsibility to find solutions to limit our "footprint" and preserve the environment for future generations. Currently, there several plans that exist to battle this threat. The most noteworthy plan is the Paris Agreement, which is an agreement made by the United Nations Framework Convention on Climate Change (UNFCCC). The goal of this agreement is to keep the global temperature below 2°C and strive to limit it further to 1.5°C. In order to achieve this objective, Nationally Determined Contributions (NDCs) have been submitted by countries outlining their post-2020 climate actions (UNFCCC, 2015).

The topic of Global warming is not just a concern of global leaders and the scientific community. Its effects are a major concern for people all around the world. A report released last year by the Intergovernmental Panel on Climate Change states that “people around the world agree that climate change poses a severe risk to their countries, according to a 26-nation survey conducted in the spring of 2018. In 13 of these countries, people name climate change as the top international threat” (PEW Research Center, 2019). These beliefs have resulted in many environmental protests and pressure on country leaders to search for solutions that are environmentally safe and sustainable.

This has led many countries to develop a strategy to replace all fossil fuel related energy systems with renewable energy sources, such as solar and wind power. According to the Center for Resource Solutions, “renewable energy sources can be used to produce electricity with fewer environmental impacts. It is possible to make electricity from renewable energy sources without producing CO2, the leading cause of global climate change” (CRS, 2019). This strategy also strives for the improvement of efficiency across all energy sectors such as residential housing, industrial manufacturing and transportation. To achieve this solution would require a lot of re-structuring of the entire energy system resulting in high installation costs, renovating costs and land usage. Furthermore, populations and urbanisation will continue to increase over time resulting in the demand for energy to increase as well. Consequently, the need for more energy will make it more challenging to substitute the use of fossil fuels and nuclear power with a renewable alternative. Even though, this strategy may be challenging to implement, some countries are still striving to implement as much renewable energy as possible. Switzerland is one of those countries determined to incorporate this strategy, while also completely phasing out the generation of nuclear power by 2050.

It will be a challenge for Switzerland to fill the gap left by the shutdown of nuclear power, while simultaneously maintaining low carbon generation and high standards of supply security. They do have a slight advantage, compared to other countries, as they already possess the “lowest carbon intensity among all International Energy Agency (IEA) countries, owing largely to the carbon free electricity sector that is dominated by nuclear and hydropower generation. However, since the people voted for the shutdown of nuclear power, Switzerland’s energy sector is now undergoing a considerable transition” (Energy Policies of IEA Countries, 2018). The country’s Energy Strategy 2050 helps to address this transition by providing a plan towards a low-carbon economy, consisting of higher energy efficiencies and renewable sources.

It is safe to assume that the overall goal of many countries is to produce all of their energy with only sustainable, renewable sources. According to the Swiss Federal Office of Energy (SFOE), Switzerland can already generate enough electricity to meet its own demand (SFOE, 2018). Since they import 100% of their fossil fuels for heating and transportation, eliminating and substituting their fossil fuel contributions with renewable sources would move them closer to complete self-sufficiency (SFOE, 2018). Therefore, this report will examine if there is any possibility for them to achieve complete self-sufficiency.

The first and second measures of the Swiss Energy Strategy 2050 (SES 2050) will help to achieve this goal since they involve: 1) Increasing energy efficiency of buildings, mobility, industry and appliances 2) Increasing the use of renewable energy and 3) withdrawing from nuclear energy. The third measure will make self-sufficiency more challenging since nuclear energy contributes to about one-third of the Swiss energy production (SFOE, 2018).

1.1 Project Aim and Objectives

The aim of this project is to answer the question; can Switzerland become self-sufficient by 2050? In order to answer this topic question, a few objectives have been set to ensure a detailed evaluation. These objectives consist of answering the following sub-questions:

- What is the current supply and demand of Switzerland regarding different energy carriers (yearly and seasonal figures)?
- What are some scenarios for achieving self-sufficiency (monthly and yearly total) without nuclear, imports or fossil fuel contributions?
- How much would it cost to maintain each scenario?
- How much CO2 emissions are produced annually from each scenario?
- What would each scenario of complete self-sufficiency look like when simulated with the Swiss ENERGYScope calculator tool?

2 Methodology

This section describes the methods chosen for the analysis of the research question. It describes the step-by-step process used to gather, organize and analyse the data to develop the scenario results. It also describes what tools were used to systematically evaluate the proposed scenarios. A methodology diagram is provided to help communicate the overall thought process.

2.1 Description of Method

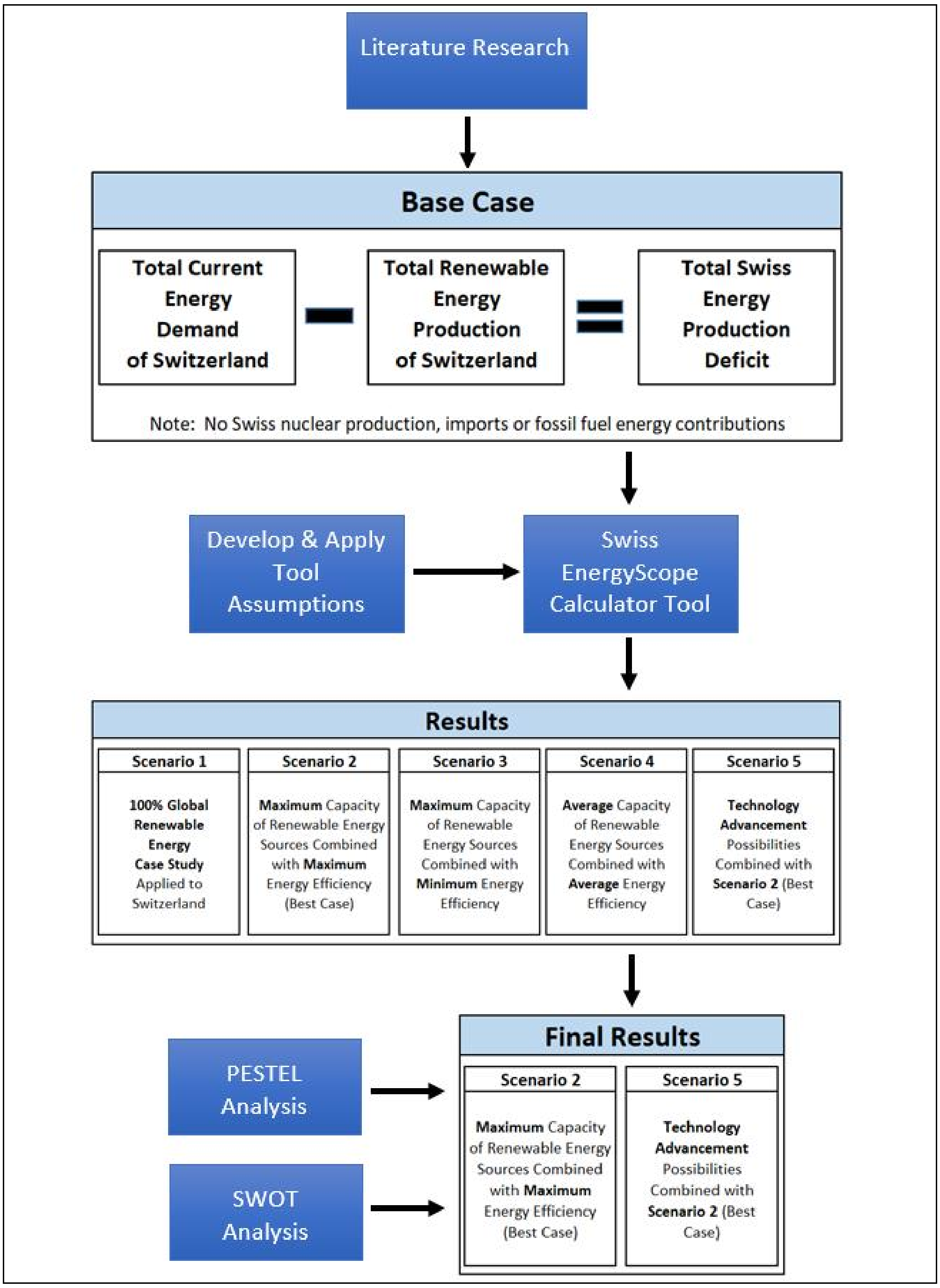

Figure 2: Methodology Diagram

The process begins with analysing the entire energy supply and demand of Switzerland, through data and literature research. Information regarding all aspects of the current situation of Switzerland's energy is necessary to begin the analysis. This information contributes to the establishment of a "Base Case" for developing viable scenarios of self-sufficiency. The initial research includes defining the current total yearly and seasonal energy demand along with details on how the energy supply was procured. This consists of all energies produced within Switzerland, along with the values of all energies being supplied by other countries. The goal of the "Base Case" is to determine how much energy is required to equal demand after applying the stipulations of the report and the Swiss Energy Strategy 2050 (SES 2050) measures. This involves excluding the contributions of nuclear energy as a source of production, since Switzerland will deactivate all nuclear reactors by 2050. In addition, all fossil fuels consumed within Switzerland will also be excluded since they are 100% imported (SFOE, 2018). As a result, the total amount needed for self-sufficiency is found by subtracting the total renewable energy production from the total energy demand. In turn, this deficit value establishes a starting point or "Base Case" for this report.

Once this value is recognised, multiple scenarios can start to be developed using multiple case studies and the Swiss ENERGYScope calculator tool. This tool makes it easier to simulate and observe the amount of energy that is required by renewable sources to cover for the discontinuation of nuclear, imports and fossil fuels. However, some preliminary assumptions are first applied to the calculator tool in order to remain consistent and provide analysis simplicity. Hence, the most relevant parameters considered within this report are in relation to the three measures of the SES 2050. This includes determining the theoretical minimum and maximum energy outputs of the different types of renewable energy sources, as well as the minimum and maximum energy consumption of housing, industry, mobility and appliances in Switzerland for 2019.

The next step is to ascertain the numerical values for each relevant parameter. The published "Prognos" report from 2012, titled ''The Energy Perspective of Switzerland until 2050'' (translated from German) was heavily relied upon for establishing these values. The report provided data for 2012 along with estimations and scenarios for 2035 and 2050 (PROGNOS, 2012). However, to be more precise it is reinforced by a collection of supplementary sources to strengthen the accuracy of the values.

This data is then applied to the parameters within the Swiss ENERGYScope calculator tool as well as the ''zero values'' for nuclear energy, imports and fossil fuels. The input of this data produces a graph for each headline: Final Energy, Electricity, Renewables, CO2, Waste, Coal and All. From these graphs, it is possible to get an overview of the entire energy system balance of Switzerland. Each parameter is "linked" within the calculator tool, meaning that when one parameter is adjusted, the other parameters respond accordingly. For example, if only the solar energy production is increased, then the total energy supply increases and the total CO2 decreases. The same connection works for the efficiency of buildings: the higher the efficiency, the more the total energy demand decreases. From this information, once all data is input into the calculator, it is then possible to determine self-sufficient scenarios and choose the option that works best in relation to cost, CO2 emissions and applicability. (See **Table 1** below for the list of the most relevant SES 2050 parameters).

		Input Parameters	Sub-parameters	Adjustable "Sliders"	Unit
		Socio-Economic		Population	millions
				Economic growth	%/year
Swiss Energy Strategy 2050	Measure 1	Energy Efficiency		Building: specific demand	kWh/m2
				Industry: energy intensity	kWh/CHF
				Appliances: average consumption	kWh/ houshold
				Lighting: average consumption	kWh/m2
		Transport		Public transport	%
				Freight transport by train	%
				Biofuels	%
			Vehicle types:	Battery Electric Vehicles	%
				Hybrid vehicles	%
				Natural gas vehicles	%
				Hydrogen vehicles	%
				Gas/Diesel vehicles	%
	Measure 2	Electricity	Renewables:	Solar PV	GW
				Wind turbines	GW
				Hydro dams	GW
				Hydro run-of-river	GW
				Deep geothermal	GW
				Seasonal storage (synthetic fuel)	yes/no
	Measure 3		Non-renewables:	Nuclear power plants	GW
				Gas power plants	GW
				Coal power plants	GW
				CO2 capture & storage	GW

Table 1: Relevant Parameters & Sub-parameters of the ENERGYScope Calculator Tool

Once multiple scenarios are developed, they are examined to see if they meet the preliminary qualifications of the report. To successfully qualify means that they are able to meet energy demand at every moment throughout the year and reach Switzerland's CO2 2050 goals. The scenarios that qualify are further analysed using a PESTEL and SWOT analysis. The results from this analysis help to give a deeper understanding of the positive and negative internal/external impacts affecting each scenario.

2.2 PESTEL Analysis

Once the different scenarios have been developed, they will be analysed using the PESTEL analysis. PESTEL is an anagram for a tool used to thoroughly analyse the situation of a topic. (See **Figure 3** below for a more detailed description).

Figure 3: PESTEL Analysis description (Edwards, 2014)

Advantages of PESTEL analysis

By helping you to understand how external factors affect your businesses, PESTEL can help you:

- determine their long-term effect on the performance and activities of your business
- review any strategies you have in place
- work out a new direction, product or plan for your business
- identify solutions to problems
- gain strategic advantage on competitors

Figure 4: PESTEL Advantages (NI Business Info, 2019)

It requires the investigation into six different categories in order to offer insight into all areas of the report. It was chosen because it helps evaluate the validity and likelihood of the results and provides awareness of how each scenario is influenced by its respective surroundings.

2.3 SWOT Analysis

The SWOT analysis highlights the aspects of the results that are beneficial and detrimental to success. It gives understanding into what aspects are the most helpful to achieve each scenario and what aspects hinder it from implementation. When implementing new ideas or systems it is advantageous to gain as much insight as possible. This knowledge can be used to develop strategies for reducing the impacts of weaknesses and threats, as well as magnifying the influence of strengths and opportunities.

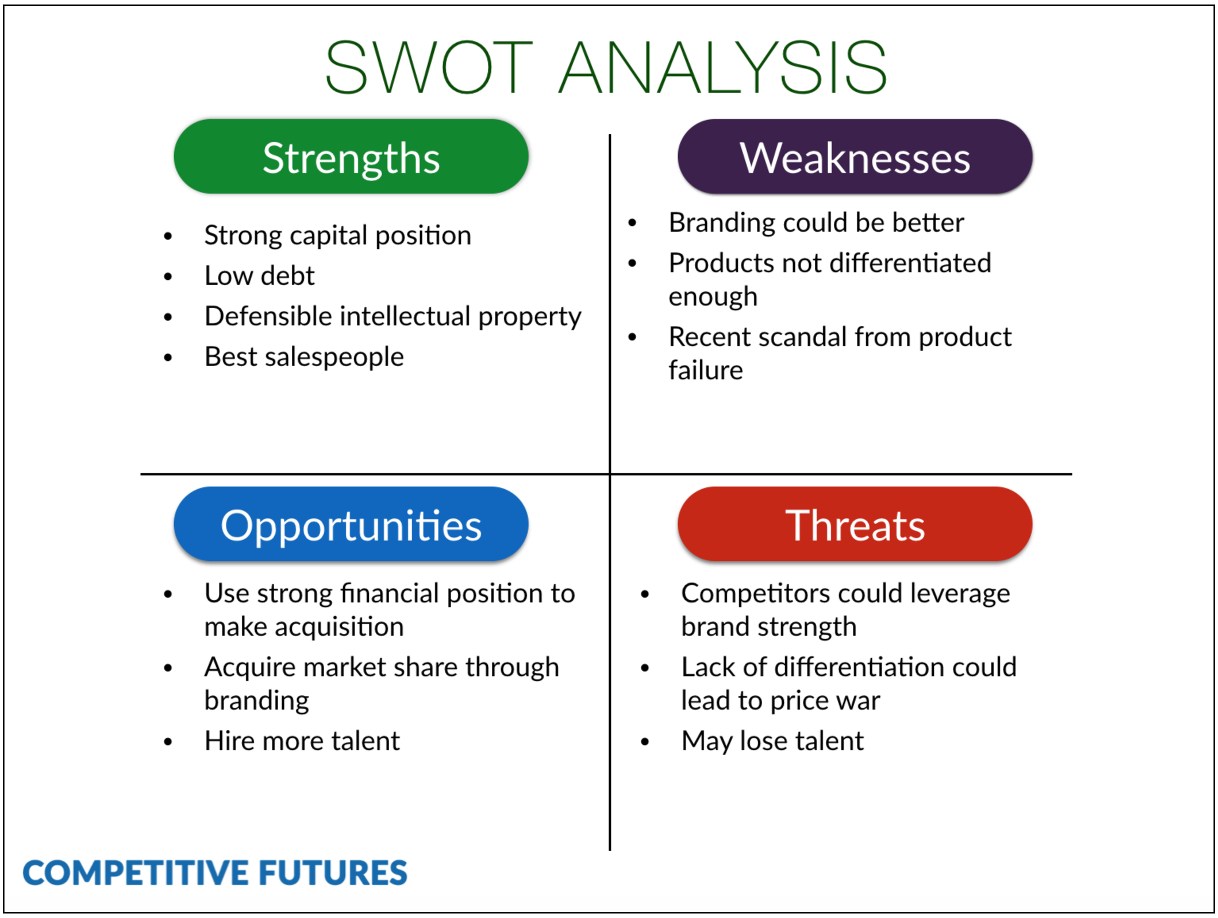

Figure 5: SWOT Analysis Example (SWOT Analysis, 2015)

3 Literature Review

The aim of this section is to present an overview and background of some of the literature research used in association with the topic of this report. A variety of sources such as journals, web articles and books, helped to develop an understanding of the current situation and provide estimations for future capabilities of the energy sector. The information provided in this section contains topics used to critically evaluate scenarios of energy self-sufficiency.

3.1 Small Countries Can Also Lead the Way with Renewable Energy

One of the countries leading as an example for the rest of the world is Norway. They have a population of only about 5.4 million people but rank number nine worldwide in renewable energy generation (WorldAtlas, 2018). They are able to meet 97% of their electricity demand with their 947 hydropower stations, with the remaining 3% consisting of wind, waste, biofuels and natural gas (IEA, Norway, 2019). The table below shows the comparison between Norway, Switzerland and the rest of the world.

Rank	Country	Total Renewable Energy (GWh)	Population
1	China	1,398,207	1,439,323,776
2	USA	572,409	331,002,651
3	Brazil	426,638	212,559,417
4	Canada	418,679	37,742,154
5	India	195,242	1,380,004,385
6	Germany	193,735	83,783,942
7	Russia	170,077	145,934,462
8	Japan	169,660	126,476,461
9	Norway	140,240	5,421,241
10	Italy	109,962	60,461,826
11	Sweden	103,067	10,099,265
12	Spain	95,660	46,754,778
13	France	90,940	65,273,511
14	United Kingdom	87,083	67,886,011
15	Turkey	81,911	84,339,067
-	Switzerland	41,305	8,654,622

Table 2: Top 15 Countries with the Most Renewable Energy (WorldAtlas, 2018) (Worldometers, 2019)

It can be argued that Norway's renewable energy success is based on "luck" due to their geographical location; their land borders the sea and consists mostly of steep valleys and mountainous regions, making it a prime location for hydropower plants and on/off-shore wind farms. However, their governments' commitment to achieving its energy goals sets them apart from most countries. In 2018, they became the first country to outlaw deforestation (Nace, 2016). On May 24, "Norway committed to zero deforestation, reports UN partner Climate Action. The ground-breaking move means that the nation pledges to ban any product in its supply chain that contributes to the deforestation of rainforests through the government's public procurement policy (Wanshel, 2016).

Furthermore, the government has proposed a ban on fossil fuel cars, prohibiting the sale of all petrol and diesel vehicles by 2025 (Dugdale, 2018). According to Secretary General Christina Bu of the Norwegian EV Association, to accomplish this goal, Norway does not make electric cars more affordable to the population but rather it "makes gas and diesel-powered cars far more expensive than they are in other countries. Taxation on gas and diesel vehicles turns into incentives for electric vehicles, whether powered via batteries or fuel cells. Collectively these zero-emission vehicles (ZEV's) have no value-added tax, which is 25 percent on gas and diesel vehicles. There is no registration tax on used car sales, no annual ownership tax, and no fuel tax. Road tolls are "fully or partially" exempt, ferry fares are "strongly reduced," bus lanes are mostly open to ZEV's, public parking fees are [eliminated] for ZEV's and there is plenty of free charging for [Battery Electric Vehicle's]" (Duffer, 2019).

Norway is also ranked as one of the top ten countries in the world for producing oil and natural gas. In 2015, crude oil and natural gas accounted for 40% of the country's total export value and approximately 17% of the country's GDP (Exports of Oil and Gas, 2019).
However, Norway exports almost all of their gas and invests a large amount of money into renewable energy and environmental efforts. In 2015, they donated 1 billion dollars to Brazil in order to help stop the deforestation of the rainforest (Wang, 2015).

3.2 Policies

The improvement of energy efficiency and renewable energy production relies very heavily on the leadership of the government and its policies. For anything to be successful, i.e. a company, leadership must always start from the top. According to the Global Status Report, "energy efficiency policies come in the form of incentives or outright mandates, such as energy performance standards for appliances and equipment, building energy codes and vehicle fuel economy standards" (REN21, 2019). Policies can be the difference between a project "going forward" or "dragging on" for years. Therefore, the governments' involvement is instrumental to establishing a strategy and accomplishing a country's energy goals. The current goals of the European Union can be seen below in **Figure 6**.

> The 2030 climate and energy framework includes EU-wide targets and policy objectives for the period from 2021 to 2030.
>
> Key targets for 2030:
>
> - At least 40% cuts in **greenhouse gas emissions** (from 1990 levels)
> - At least 32% share for **renewable energy**
> - At least 32.5% improvement in **energy efficiency**
>
> The framework was adopted by the European Council in October 2014. The targets for renewables and energy efficiency were revised upwards in 2018.

Figure 6: Energy Goals of the European Union by 2030
(EuropeanCommission, 2030 climate & energy framework, 2019)

One of the goals is to globally reduce the amount of CO_2 emissions being released into the atmosphere. Countries all over the world are getting more involved to reduce CO_2 emissions and improve the health of our planet. To accomplish this, the focus on policies to improve energy efficiency and increase renewable energy production has become a high priority. According to an executive director of IEA, Faith Birol, "the right efficiency policies could enable the world to achieve more than 40% of the emissions cuts needed to reach its climate goals without new technology" (IEA, 2018). She also states that there are other benefits for countries besides helping the planet, "efficiency can enable economic growth, reduce emissions and improve energy security" (IEA, 2018).

So far, governments are making a big difference in improving energy efficiency in the end-use sectors of buildings, industry and transport. They are making a big difference and are receiving appropriate credit for their actions. For example, "policies supporting energy efficiency in the European Union (EU) have been credited with advancing the share of renewable heat in buildings to 22% in 2017, as the demand for heat in the region stabilised and dipped slightly between 2012 and 2017 (-0.3%), making the EU the only region in the world where heat demand is declining'' (REN21, 2019).

Coal consumption fell for the sixth year in a row in Europe, due to climate policies, increased competition from renewables and gas, and higher CO2 emissions costs in the European Union (REN21, 2019). The impact of efficiency policies has made a large contribution over the last 20 years. Worldwide, the "efficiency gains since 2000 prevented 12% more energy use than would have otherwise been the case in 2017. Energy efficiency is a major driver for uncoupling energy consumption from economic development'' (REN21, 2019).

3.3 Synthetic Gas for Transportation and Heating

Currently, there are zero countries who are completely self-sufficient in generating enough energy to meet their total energy demand. The transportation sector is one of the main reasons for this since it makes up a large portion of a country's demand and alternative mobility technologies are underdeveloped. Furthermore, more than a half of the world's countries are unable to supply their own oil. The total world production in 2019 was estimated to be around 80.6 million barrels/day with contributions from 96 countries (USEIA, 2019). The top three producers were the United States with over 15 million barrels/day, followed by Saudi Arabia with 12 million barrels/day and Russia with 10.8 million barrels/day (USEIA, 2019). This results in 99 out of 195 countries in the world who cannot produce oil. According to Gal Luft, who is a senior adviser to the United States Energy Security Council, "as long as hydrocarbons dominate both our electricity and transportation systems, most nations will never be able to achieve self-sufficiency and will continue to rely on the global energy trading system" (Luft, 2012). Therefore, finding a renewable solution for transportation will have a huge impact on self-sufficiency. Synthetic fuel is used in the results of this report as a possible solution to both heating and mobility since it is supported by many literature resources who believe in its potential.

Natural gas is currently one of the largest fossil fuel resources in the world. In 2018, it contributed to almost one-fourth of the world's consumption with 23%. In comparison to other fuels, it was ranked number three in the world, only trailing coal with 26% and oil at 32% (Enerdata, 2019) (See **Figure 7** below). It does not show any signs of slowing down either, as major players such as the U.S., China and India continue to consume more each year as a substitute for coal (Enerdata, 2019). Even though, it burns "cleaner" than coal and emits 50 to 60 percent less CO2 into the atmosphere when combusted in a new, efficient natural gas power plant, it still has many environmental health risks (NETL, 2010). The primary component of natural gas is methane, which is 86 times stronger than CO2 at trapping heat over a 20-year period and 34 times stronger over a 100-year period (Myhre, 2013). Therefore, any leakage when being drilled, extracted or transported can contribute significantly to the greenhouse gas (GHG) effect. Furthermore, when it is burned it produces nitrogen oxides (NOx) that contribute to the production of smog and is linked to problems such as asthma, bronchitis, lung cancer, and heart disease (CalEPA, 2012). Even though, using natural gas as a substitute for coal has its benefits, it is not a desirable, healthy and sustainable solution. However, *synthetic gas* seems to have many promising opportunities for the future.

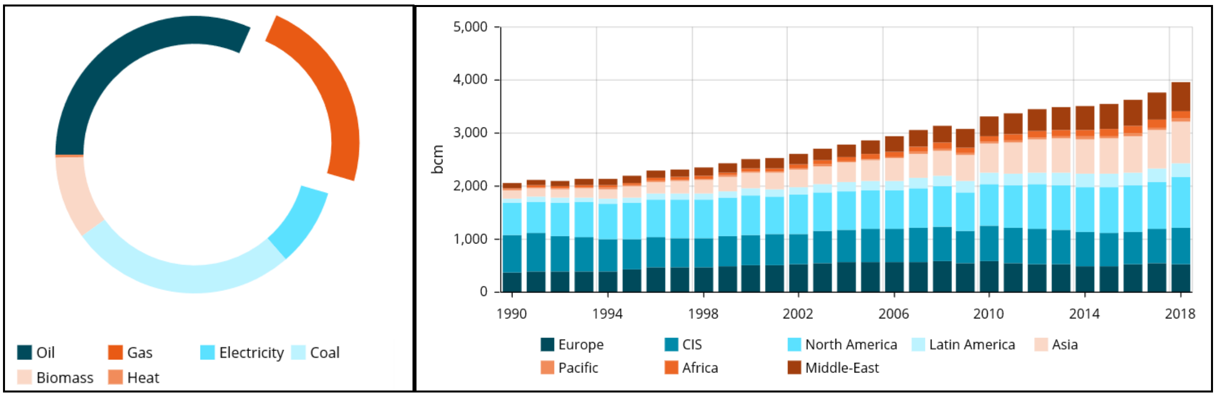

Figure 7: Global Natural Gas Consumption "Overall" and in "Billion Cubic Meters (bcm)" (Enerdata, 2019)

An article published in a journal, titled "Fuel", states that "synthetic natural gas production is a promising way to solve the problems related to the limited availability and the constant increases in natural gas prices (A. Molino, 2015). Methanation of synthetic gas deriving from biomass gasification has the great advantage of producing biomethane, which could be directly injected into the distribution grid without any infrastructural cost (A. Molino, 2015). This means synthetic gas could be substituted into natural gas production plants with only small machinery modifications. This would make the implementation and transition phase much less complicated.

Another positive aspect of synthetic gas is that it has the ability to choose from multiple sources of feedstock to yield the same product. Even if the plant originally produced fuels solely from coal, it can be switched over to another source, making the infrastructure forward compatible (Speight, 2015). According to one report, "many countries could eliminate the need for crude oil by using a combination of coal, natural gas, oil shale, non-food crops to make synthetic fuel, as well as waste carbonaceous materials" (Speight, 2015). It is also capable of using more than one source at the same time, i.e. coal with biomass, to create a hybrid solution. This will allow natural gas companies to reduce the amount of fossil fuels being used in their current industrial processes, as they make a smoother transition to 100% biomass. In the case of hybrid BCTL plants, some facilities are already planning to use a significant amount of biomass alongside coal (Speight, 2015). Ultimately, given the right location with good biomass availability, more natural gas plants can be transitioned from coal or gas to produce a more sustainable and renewable fuel source for heating and transportation.

Two successful companies and manufacturers of some of today's high quality products, Audi and Bosch, are diving deeper into research regarding synthetic fuels. The CEO of Bosch stated, "Synthetic fuels can make gasoline- and diesel-powered cars carbon-neutral" (BOSCH, 2019). Moreover, Audi is systematically building on its e-fuels strategy with its partners, Ineratec GmbH and Energiedienst Holding AG. A new building facility built in 2018 for producing e-diesel is located in Laufenburg, Switzerland. (Volkswagen, 2019). Audi's e-diesel "has the potential to make conventional combustion engines operate almost CO2-neutrally" (Volkswagen, 2019). The e-diesel is produced using the power-to-liquid method and converts surplus hydropower into synthetic fuel. The power-to-liquid process consists of using the "green power" generated by a hydroelectric power station to produce hydrogen and oxygen from water by means of electrolysis. The hydrogen reacts with "CO2 from the atmosphere or from biogenous waste gases and, as with all Audi e-fuels, is the only source of carbon". Furthermore, the greatest advantage of the e-diesel is that the combustion engines using synthetic fuels can continue to use the existing filling-station network (BOSCH, 2019). This is very important regarding the ease of implementation.

The most common process for creating synthetic gas is the Fischer-Tropsch gasification method. There are three core advantages to using this process (Chadeesingh, 2011; Speight, 2008, 2013a) (Speight, 2015):

- Fuels are compatible with current diesel- and gasoline-powered vehicles and fuel distribution infrastructure. These fuels do not require new or modified pipelines, storage tanks, or retail station pumps.

- There is reduced reliance on imported petroleum and increase energy security.

- Little or no particulate emissions exist because Fischer-Tropsch fuels have no sulfur and aromatics content, and there are fewer hydrocarbon and carbon monoxide emissions.

In terms of application, J.G. Speight believes that the most realistic approach “would call for a gradual implementation of synthetic fuel technology, and it would take 30 to 40 years for the United States to fully adopt synthetic fuel production in a way that it could supplement petroleum supplies” (Speight, 2008, 2011a, 2011b). The economics of synthetic fuel production, including the capital costs, can still approach profitability depending on processes used and which type of feedstock applied. To incorporate this new type of fuel “would take decisions by typically indecisive governments to support country-wide synthetic fuels industries. It is the perennial question: What is a country willing to pay for energy independence?” (Speight, 2015).

3.4 Swiss Energy Strategy 2050

The original energy strategy consisted of “four pillars: energy efficiency, renewable energies, replacement and new construction of large power stations for electricity production (also nuclear power stations), and foreign energy policy” (SFOE, 2018). However, they have also decided to increase the intensity of implementing renewable energy sources and improving energy efficiency. This resulted in the Swiss Energy Strategy 2050 consisting of three fundamental measures.

3.4.1 Measure 1: Increasing Energy Efficiency

The goal of this measure is to reduce the energy consumption by promoting higher efficiency from buildings, industry, mobility and appliances. According to the Swiss Federal Office of Energy (SFOE), “more than 40% of energy consumption and about a third of climate-damaging CO2 emissions are attributable to the building industry” (SFOE, 2018). Therefore, the Federal government would like to improve upon this sector as much as possible. To accomplish this, the government decided to offer subsidies to pay for costs of building renovations. The Renewables 2019 Global Status Report also agrees that building renovation should be a leading priority, stating ‘’factors that have been most effective in mitigating the growth in energy demand include; efficient energy systems and appliances in buildings, as well as improved building envelopes (such as glazing and insulation)’’ (REN21, 2019).

However, since energy efficiency is higher amongst new buildings than older buildings, the government aims to promote demolition and construction of new buildings. Since the establishment of the Energy Strategy 2050 Act, “it is now possible to deduct the costs of demolition to make way for a new building. Together with the costs of energy-related improvements, demolition costs can be deducted also in the next two tax periods if it is not possible to fully offset the expenditure in the year in which it was carried out” (SFOE, 2018). They even use a large amount of money, generated from CO2 levies on fuels, to help pay for these renovation costs. However, the method of completely demolishing a building to construct a new one has many concerns and questions about the amount of waste generated. Whether this is the right approach is up for debate, but this example shows how serious the Swiss government is about improving its overall energy system.

The overall results of the involvement of governments throughout the world has provided some positive effects. The energy intensity of space heating has “contracted nearly 18% between 2010 and 2017 (REN21, 2019). This contributed to the highest share of energy efficiency savings in buildings during this period, followed by lighting and space cooling, which is increasingly efficient even as its overall energy intensity has risen due to rapid demand growth’’ (REN21).

In regards to the mobility/transportation sector and in accordance with European Union law, Switzerland has decided to implement stricter CO2 emission regulations. On April 17, 2019 “the European Parliament and the Council adopted Regulation (EU) 2019/631 setting CO2 emission performance standards for new passenger cars and for new light commercial vehicles (vans) in the EU for the period after 2020” (EuropeanCommission, Reducing CO2 emissions from passenger cars, 2019). This new law should help reduce the impact of CO2 coming from Switzerland since all motor vehicles within the country are responsible for about one-third of all energy consumption and CO2 emissions (SFOE, 2018). The newly accepted limit of CO2/km for all manufactured passenger vehicles in 2020, will be reduced to an average of 95g CO2/km (Commission, 2019). This is equivalent to a fuel consumption of around 4.1 liters/100 km of petrol or 3.6 liters/100 km of diesel (EuropeanCommission, Reducing CO2 emissions from passenger cars, 2019). Heavier vehicles produce more CO2, therefore, delivery vehicles and light articulated trucks will be allowed a higher average of 147g CO2/km. The penalties to vehicle manufacturers for violating the regulations can be seen below in **Figure 8**. However, the new regulations don’t take effect until January 1, 2020.

Penalty payments for excess emissions

If the average CO_2 emissions of a manufacturer's fleet exceed its target in a given year, the manufacturer has to pay an **excess emissions premium** for each car registered.

Until 2018, this premium amounts to

- €5 for the first g/km of exceedance
- €15 for the second g/km
- €25 for the third g/km
- €95 for each subsequent g/km.

From 2019 on, the penalty will be €95 for each g/km of target exceedance.

Figure 8: Excess CO2 Emissions Penalty Costs
(EuropeanCommission, Reducing CO2 emissions from passenger cars, 2019)

The industry and services sector are also being encouraged to decrease energy consumption. There are “programs and projects which contribute towards more economical energy consumption in industry, the services sector and households are supported by competitive tenders” (SFOE, 2018). Competitive tendering is a method applied towards procurement of supplies or services within the construction industry, where a supplier or contractor with the lowest bid is awarded the contract. The suppliers who are “tendering for a contract are often competing with others, and generally, none of the tenderers are aware of the quotes provided by each other; therefore, they are incentivised to submit their most competitive tender” (Competitive tender, 2019). The projects with the best cost-benefit ratio get a chance to compete in an auction to win promotional subsidies. The financing of these subsidies are funded by “the grid surcharge that electricity consumers pay to promote renewable energies and energy efficiency” (SFOE, 2018).

3.4.2 Measure 2: Increasing Renewable Energy Sources

The Swiss government is promoting the expansion of all renewable energy sectors. According to the Swiss Federal Office of Energy, “the revised Federal Energy Act aims to promote the use of domestic renewable energy. This includes conventional hydropower production as well as newer renewable sources such as solar power, wood, biomass, wind power and geothermal energy. The use of renewable energy is highly beneficial: the more we use renewable energy, the less dependent Switzerland will be on imported fossil fuels” (SFOE, 2018).

There has been a large improvement in technology regarding solar, wind, geothermal and biomass energy. However, the cost of instalments are higher than the price at which this electricity can be marketed (SFOE, 2018). The government is offering subsidies in order to help pay for the installation costs. Under the SES 2050, the government has improved the “current maximum grid surcharge of 1.5 cents per kilowatt hour” to a maximum of “2.3 cents per kilowatt hour in order to promote the building of more such installations” (SFOE, 2018). Furthermore, “the feed-in remuneration will be brought closer into line with the market situation by virtue of the fact that most of the energy producers will have to sell their electricity directly on the market. In this way they will have an incentive to sell electricity when it is in short supply and thus fetches a higher price” (SFOE, 2018).

The operators of smaller photovoltaic installations, with a production capacity of less than 30 kilowatts, are able to apply for a one-time subsidy towards the investment costs of the installation (SFOE, 2018). This one-time investment grant covers a maximum of 30% of the investment costs of a comparable installation. The SES 2050 makes it “possible for larger solar PV installations to also benefit from one-time investment grants” (SFOE, 2018).

Furthermore, new large-scale hydroelectric power stations with a production capacity of more than 10 MW are also able to receive investment subsidies. To pay for these subsidies, a “grid surcharge” is added to the electricity bill of Swiss citizens. Currently, these investment subsidy contributions will be available until 2030 at the latest (SFOE, 2018).

3.4.3 Measure 3: Phase-out of Nuclear Energy Reactors

Following the Fukushima disaster in 2011, the Swiss Federal Councillor Doris Leuthard announced on March 14, 2011 a freeze in the authorisation procedures for three new nuclear power plants and ordered a safety review of the country's existing plants (SFC, 2011). She was also apprehensive about the risk of the Fessenheim Nuclear Power Plant, located in France, which is only approximately 40 km from the Swiss border (YahooFrance, 2011). Therefore, a safety inspection was ordered, followed by a vote from the Grand Council of Basel-Stadt on April 6, 2011. The voting concluded that operations would be set in motion for the eventual closure of the plant. It is currently still open but the closure is scheduled for the summer of 2020 (AFP, 2018).

Furthermore, a few months after Fukushima, the Swiss Federal Council and Parliament decided to completely phase out their five nuclear reactors by 2050 (Energy Policies of IEA Countries, 2018). They combined this new measure with the other pre-existing measures stemming from their Energy Strategy in 2007 to form the new SES2050. The existing nuclear power stations will shut down at the end of their technically safe operating life and will not be replaced with new ones. The first nuclear generator will close in 2019 and the last one will be shut down no earlier than 2035 (Energy Policies of IEA Countries, 2018).

The president of Switzerland's Green party, Regula Rytz, praised the voting results as a "moment of historic change". She continues by saying, "the Swiss population has said 'no' to the construction of new nuclear power plants and yes to the development of renewable energy. The conditions have also been set whereby the economy and households will need to take responsibility for the future" (Switzerland votes to phase out nuclear power, 2017).

The five nuclear power plants: Beznau I & II, Mühleberg, Gösgen and Leibstadt. In addition to the nuclear power plants, there are three research reactors in operation: the Paul Scherrer Institute in Würenlingen, the Swiss Federal Institute of Technology (ETH) in Lausanne and the University of Basel and the National Central Interim Storage Facility for Radioactive Waste (ZWILAG) at Würenlingen (Nuclear facilities in Switzerland, 2019). All nuclear power plants are monitored by the Swiss Federal Nuclear Safety Inspectorate (ENSI), which is the national regulatory authority with responsibility for nuclear energy (Nuclear facilities in Switzerland, 2019). A map of the five nuclear power plant locations can be seen in **Figure 9** below.

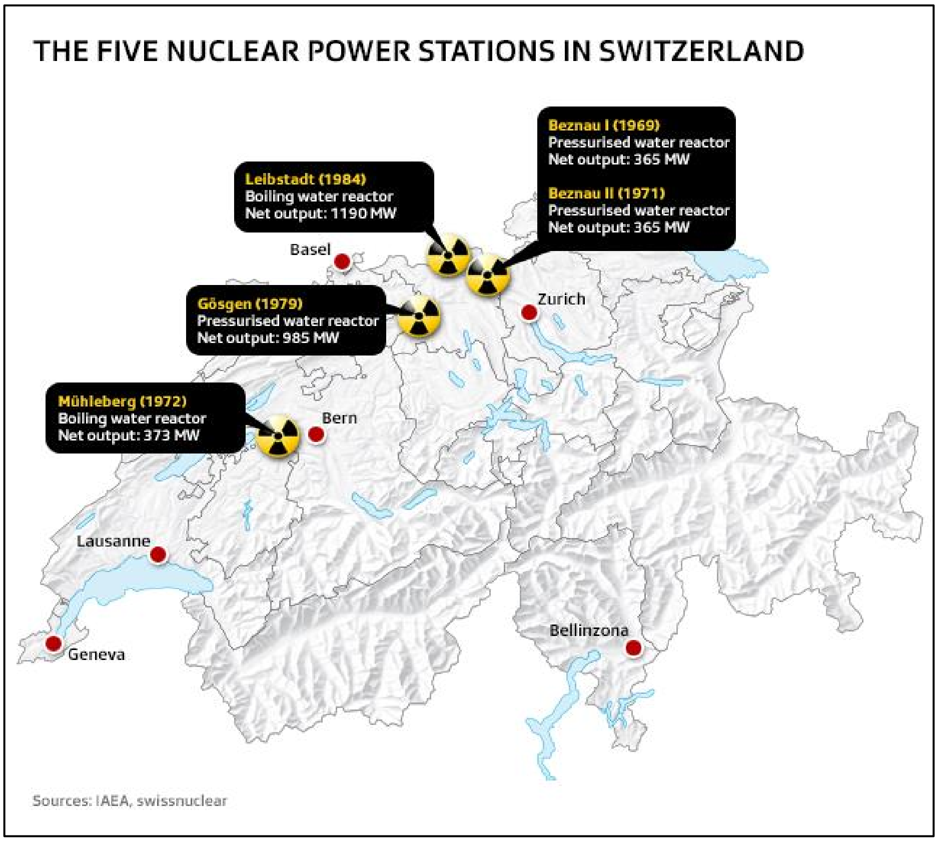

Figure 9: The Five Swiss Nuclear Reactors (Misicka, 2019)

The radioactive waste from nuclear power plants is in the tens of thousands of tons in Switzerland and its management is the responsibility of the respective producer. The waste from nuclear power plants is stored at surface sites until it is moved to permanent underground locations. Up until 2016, processing of nuclear waste was mostly done overseas, however, a 10-year moratorium on its export was issued in 2016 (Luigi Jorio, 2019).

3.5 Current Swiss Situation

The energy data from 2019 is not currently available; therefore, data from 2018 will be used as the "current" data for this report. Switzerland's major sources of energy are water and nuclear power. In 2018, hydropower accounted for 55.4% of domestic electricity production, while the country's five nuclear power plants generated 36.14%. Combined, these two sources make up about 91% of the country's domestic energy/electricity production. Since the total energy production amount contributes entirely to electricity, the terms "energy" and "electricity" can be considered the same. Solar, wind, biomass and geothermal power production is very low and does not make any significant contribution to the Swiss energy supply. There is zero domestic fossil fuel resources, therefore, Switzerland relies 100% on imports to supply its oil, coal and natural gas. **See Table 3** below for the complete list of energy production sources and quantities.

Current Swiss Situation			
	Source	Amount (GWh)	%
Total Energy (Electricity) Production	Solar PV	1,944	2.88%
	Wind	122	0.18%
	Hydro	37,428	55.40%
	Geothermal	0	0.00%
	Other Renewables	1,811	2.68%
	Nuclear	24,414	36.14%
	Thermal & District Heating (non-renewable)	1,839	2.72%
	Gross Total	**67,558**	100%
	Storage pumps	-3,987	
	Net Total	**63,571**	

Table 3: Total Swiss Energy Production of 2018
(SFOE, 2018)

Switzerland currently has a Total Final Consumption (TFC) of about 230,800 GWh/year. The transport sector requires the most energy comprising of about one-third of the total consumption. This is due to the high amount of non-electrical energy, such as benzene and diesel, used to power 2-passenger vehicles. However, public transport powered by electricity is also a large contributor. According to the IEA, "electricity used in the rail sector accounts for a large part of total transport consumption. Its use in rail transport accounted for 5% of the TFC in transport in 2016, which was the highest share in IEA member countries" (Energy Policies of IEA Countries, 2018). There has been a slow decline in the demand for transportation fuels since the adoption of stricter vehicle emission standards and investments to facilitate model shift, as well as by the recent interest of biofuels (Energy Policies of IEA Countries, 2018).

The housing sector comes in second with over one-fourth of total final consumption. This is mainly due to the energy needed to heat the country's water and homes. However, "consumption of liquid heating fuels is decreasing as buildings become more efficient and switch to renewable energies" (Energy Policies of IEA Countries, 2018). The housing sector also comprises of electricity needed for lighting, which adds to the total electricity consumption of approximately 57,647 GWh/year. This amount contributes to approximately one-fourth of the TFC. **See Table 4** below for further details of the total final energy consumption by sector and source.

Current Swiss Situation			
Total Final Energy Consumption by Sector	**Sector**	**Amount (GWh)**	**%**
	Transport	87,223	37.79%
	Households	62,206	26.95%
	Industry	41,785	18.10%
	Services	37,150	16.10%
	Other	2,436	1.06%
	Total	**230,800**	100%

Total Final Energy Consumption	**Source**	**Amount (GWh)**	**%**
	Electricity	57,647	24.98%
	Natural Gas	31,189	13.51%
	Coal	1,192	0.52%
	Wood	10,642	4.61%
	District Heating	5,389	2.33%
	Industrial Waste	3,019	1.31%
	Stationary Fuels	32,119	13.92%
	Motor Fuels	81,750	35.42%
	Other	7,853	3.40%
	Total	**230,800**	100%

Table 4: Total Final Energy Consumption of 2018 by Sector and Source (SFOE, 2018)

3.6 Swiss ENERGYScope Calculator Tool

This online tool was created by Swiss Energy Scope who are affiliated with the university of Lausanne: Ecole Polytechnique Federale De Lausanne (EPFL). It was created in 2012 as an online tool to allow the public to create their own personal scenarios in regards to the Swiss Energy Strategy 2050. Many literature sources were used, such as the Prognos Report, to estimate a range of feasible minimum and maximum parameters. Furthermore, the tool provides definitions and descriptions of the methods used to calculate the results of each parameter. The tool consists of six main input parameters, which contain many sub-parameters that can be adjusted and tailored to the user's data input. As each parameter changes, the respective bar graphs for the seven "General Indicator" headings will adjust automatically to provide a visual overall assessment of the data. Each graph can also be examined by yearly, seasonal or monthly totals. See **Figure 10** below for an example.

Figure 10: Example of Swiss ENERGYScope Calculator Tool (ENERGYScope Calculator, 2012)

3.6.1 Input Parameters

This section contains a brief description of the most essential input sub-parameters being considered in this report. As previously mentioned in the methodology section, the most essential sub-parameters are the ones pertaining to energy efficiency and renewable energy. These parameters are also the ones having the largest influence on the calculator tool according to the sensitivity analysis.

The descriptions in this section of the report are taken directly from the creators of the Swiss ENERGYScope calculator tool. Due to the complexity of the tool's construction, only minor paraphrasing was applied to the original descriptions in order to ensure accuracy. More information regarding the assumptions and parameters of the three different scenarios can be found in chapters 7, 8 and 9 of the Prognos 2012 report (PROGNOS, 2012).

Energy Efficiency

The energy efficiency parameter contains the four sub-parameters: Building, Industry, Appliances and Lighting. The respective minimum and maximum values can be seen in **Figure 11** below.

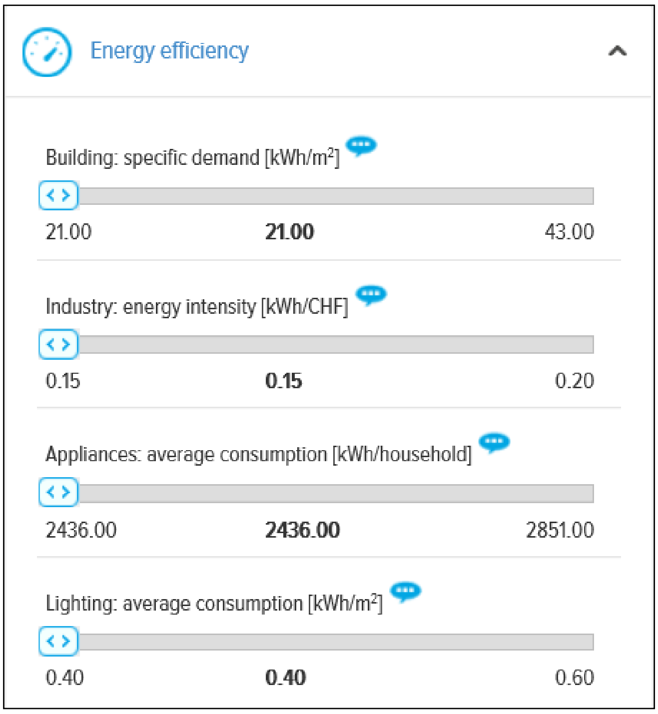

Figure 11: Energy Efficiency Sliders (ENERGYScope Calculator, 2012)

Building: Specific Demand

The energy performance of a building's efficiency is expressed in kWh/m2. This metric represents the annual average heating demand per unit of inhabited surface. The lower this value; the higher the efficiency of the building (irrespective of its size). In 2011, the average consumption of all Swiss buildings was 92 kWh/m2 (PROGNOS, 2012). According to the Prognos report, the estimated future value ranges for the average energy performance of Swiss buildings are:

- 2011: 92 kWh/m2
- 2035: 41 - 57 kWh/m2
- 2050: 21 - 43 kWh/m2

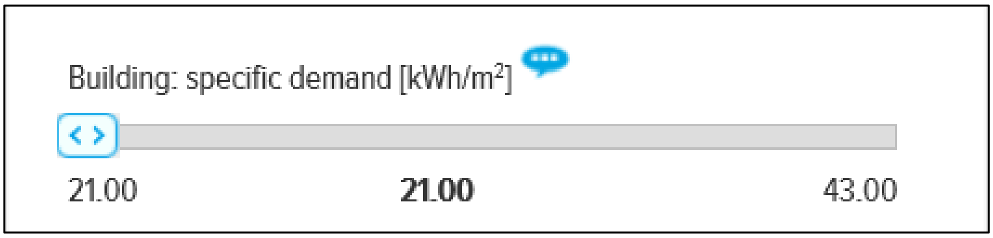

Figure 12: Specific Building Demand Slider (ENERGYScope Calculator, 2012)

The values for the annual average heating demand are taken from the three scenarios presented in Prognos 2012 (PROGNOS, 2012) and they define the max and min values for the building efficiency slider. Each scenario has a series of assumptions, as mentioned previously; one is the rate of refurbishment for buildings depending on their age. The efficiencies of refurbished/new buildings is also scenario dependent.

Annual average heating demand [kWh/m2]		
Scenarios	**2035**	**2050**
New energy policies	41	21
Political measures of the Federal Council	49.5	33
Business as usual	57	43

Table 5: Annual Average Heating Demand (PROGNOS, 2012)

Industry: Energy Intensity

The energy intensity of the industry is a parameter, which synthesises the efficiency evolution of the Swiss industry. It is expressed in kWh/CHF. This metric represents the average energy consumption of the industry for producing an amount of goods worth one CHF. The lower this value; the higher the efficiency of the industry. This indicator reflects the way heat and electricity are used in the industry sector. The major industrial energy demands come from processed heat requirements and from the electric motors that drive equipment. (PROGNOS, 2012)

In 2011, the Swiss industry energy intensity amounted to 0.34 kWh/CHF in average (PROGNOS, 2012). The expected future values of the average "Industry Energy Intensity" are:

- 2035: 0.20 – 0.25 kWh/CHF
- 2050: 0.15 – 0.20 kWh/CHF

The values for the annual average heating demand are taken from the three scenarios presented in Prognos 2012 and they define the maximum and minimum values for the industry efficiency slider:

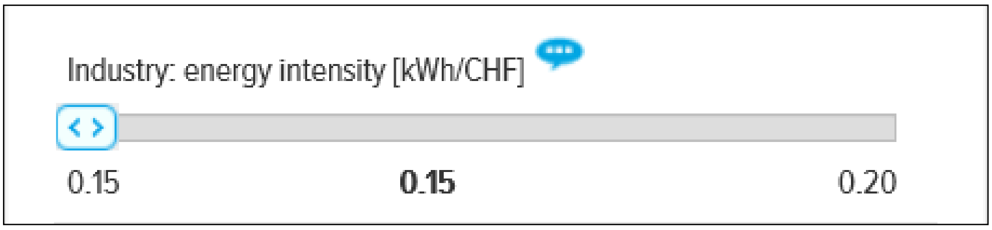

Figure 13: Industry Energy Intensity Slider (ENERGYScope Calculator, 2012)

The industry energy intensity is calculated assuming several parameters. The two main assumptions are based on:

- Evolution of the energy intensity for twelve types of industry (food, clothing, paper, chemistry, etc.).
- The evolution of the Swiss industry mix. It is necessary to forecast the production of each type of industry in order to be able to determine its weight in the Swiss industry production and calculate its contribution into the average energy intensity. (PROGNOS, 2012)

Appliances: Average Consumption

The selected parameter for measuring the appliances efficiency is the total average electricity consumption of appliances per year, in a single household. The amount for this is measured in kWh/year per household. In 2011, the appliances of households consumed an average of 2,873 kWh/year (PROGNOS, 2012). The values of electricity consumption for appliances is based off of the three scenarios presented in the Prognos 2012 report and define the maximum and minimum values for the efficiency slider:

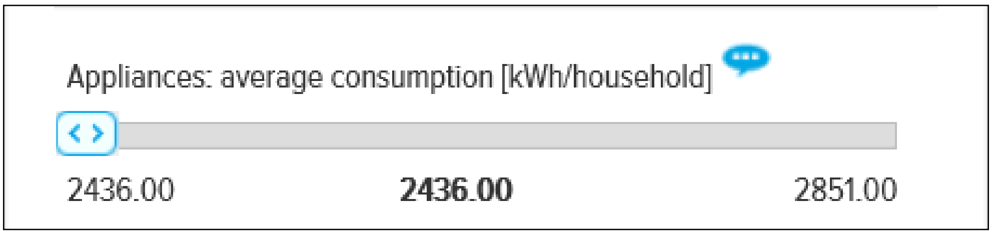

Figure 14: Appliances Average Consumption Slider (ENERGYScope Calculator, 2012)

According to the Prognos 2012 report, the estimated evolution of electricity consumption from appliances can be seen in **Table 6** below:

Appliances annual average electricity consumption of a household [kWh/(year·household)] *							
Appliance type	**2011**	**2035**			**2050**		
	2011	**BaU**	**PM**	**NEP**	**BaU**	**PM**	**NEP**
Electric stoves and ovens	401	357	344	344	342	310	304
Auxiliaries for cooking	307	281	271	263	275	253	242
Appliances (no cooking)	853	604	562	534	580	504	467
IT and audio-visual systems	431	343	324	313	329	293	282
Air conditioning and ventilation systems	350	455	416	383	659	596	526
Others	531	621	619	592	665	661	615
TOTAL	2873	2661	2537	2429	2851	2618	2436

**BaU = Bussines as Usual, PM = Political Measures of the Federal Council, NEP = New Energy Policies*

Table 6: Appliances Annual Average Electricity Consumption
(PROGNOS, 2012)

Lighting: Average Consumption

The energy performance of lighting is expressed in kWh/m2. This metric represents the annual average electricity demand per unit of illuminated surface. The lower this value is, the higher the efficiency of lighting. In 2011, the average electricity consumption per square meter for lighting in Switzerland was 3.2 kWh/m2 (PROGNOS, 2012). This number is estimated to decline tremendously by 2050 within the range of .4 to .6 kWh/m2 (PROGNOS, 2012). The switch to lighting devices that require less electrical energy per unit of light intensity (measured in lumens) provides immediate gains. Compact fluorescent lamps (CFLs) and light emitting diodes (LEDs) are the two most efficient technologies. Compared with a traditional tungsten-filament (incandescent) bulb, CFLs offer a 75% electricity saving and LEDs 80% (PROGNOS, 2012).

CFL's and LED's are available in different forms. However, LED's are not always suitable for the replacement of fluorescent tubes, due to incompatibility. Although, both offer much longer lifetimes and efficiency than incandescent bulbs. In some countries, the sale of some incandescent bulbs are no longer permitted (Switzerland only banned light bulbs of the energy efficiency class F and G) (PROGNOS, 2012).

Annual average lighting performance [kWh/m2]			
Scenarios	**2011**	**2035**	**2050**
New energy policies	3.2	0.6	0.4
Political measures of the Federal Council	3.2	0.7	0.4
Business as usual	3.2	0.9	0.6

Table 7: Annual Average Lighting Performance Estimations (PROGNOS, 2012)

The values for the lighting performance are taken from the three scenarios presented in Prognos 2012 report and define the maximum and minimum values for the lighting efficiency slider (Dr. Almut Kirchner, 2012):

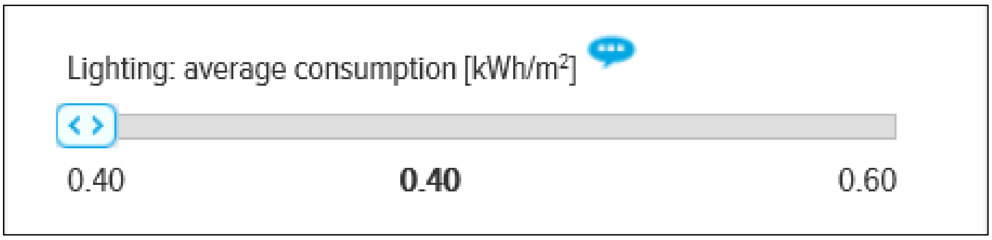

Figure 15: Lighting Average Consumption Slider (EPFL, 2012)

Transport

The transportation parameter consists of adjustable sliders regarding the percentage of vehicles used in Switzerland. With the sliders, it is possible to select the percentage of several technologies for passenger cars: electric, hybrid, natural gas, gasoline/diesel and hydrogen. It is necessary to realise that the sub-parameter "hybrid vehicles" includes two technologies: hybrid electric vehicles (HEV) and plug-in electric vehicles (PHEV). Hybrid vehicles contain a smaller amount of gasoline and diesel compared to conventional vehicles. However, since fossil fuels will not be considered as a fuel source within this report, the number of Gasoline/diesel vehicles and Hybrid vehicles will be set to "0%". The slider for Natural gas vehicles will still be considered but as a "synthetic gas".

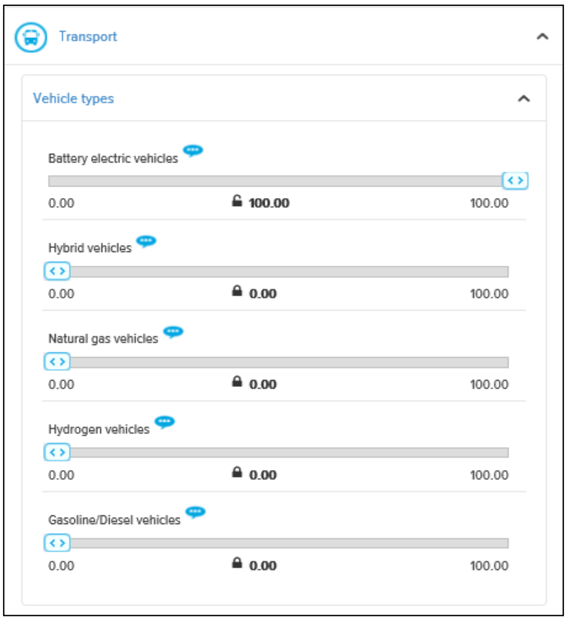

Figure 16: Transport Vehicle Types (ENERGYScope Calculator, 2012)

The Transport parameter also contains sub-parameters for the percentage of public and freight transport. The user can select the percentage of public transport, which determines the sum of train, tram/trolley and bus. The metro is not included in this report because Lausanne is the only city in Switzerland that uses it. According to a study in 2018, the number of road motor vehicles recorded in Switzerland was 716 vehicles per 1,000 people (71.6%) (Wikipedia, 2019). Therefore, for simplicity, this report assumes the remaining 28.4% of Switzerland uses public transport.

#	Country or region	Motor vehicles per 1,000 people	Total	Year
1	San Marino	1,263		2013[5]
2	Monaco	899		2013[5]
3	New Zealand	860	4,240,000	2018[6]
4	United States	838	272,480,899[7]	2017
5	Iceland	824	278,924[8][9]	2016
6	Liechtenstein	773		2016[10]
7	Finland	752	4,151,275	2019[11]
8	Australia	730	19,200,000[12]	2018
10	Brunei	721	300,897[8]	2015
9	Switzerland	716	6 113 791[13]	2018
11	Canada	685	25,060,399 [14]	2018

Table 8: Number of Vehicles per Country (Wikipedia, 2019)

The “freight transport by train” slider increases or decreases the quantity of goods (in tons-kilometer (tkm)) that is transported by train compared to trucks. In 2011, 37% of freight transport was covered by rail in Switzerland (PROGNOS, 2012). The existing infrastructure is reaching its maximum capacity and new infrastructure is increasingly expensive. Therefore, this report will assume that freight transported by rail will not deviate much in 2050, from the 37% in 2011. The percentage of Biofuels used to fuel freight trucks will be set to “100%” for this slider. However, a complete engine re-modification would be necessary to support a 100% plant based fuel. The biofuels that are currently used today contain an amount of gasoline/diesel mixed with plant material in order for the fuel to work in most typical vehicle engines.

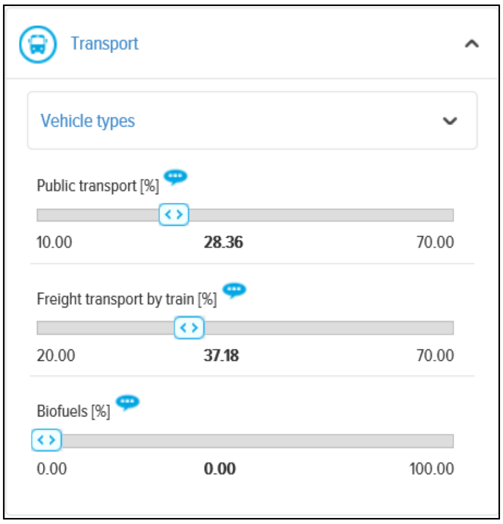

Figure 17: Public and Freight by Train Transport Slider (ENERGYScope Calculator, 2012)

Electricity

There are several ways of converting resources into electricity. Hence, the calculator tool has made the distinction between renewable and non-renewable resources, with each of their respective minimum and maximum values, estimated by the Prognos Report for 2050. The minimum and maximum values are also described in more detail in the "Discussion of Results" section of this report. The renewable resources consist of Solar, Wind, Biomass, Geothermal and Hydropower.

Electricity production from non-renewable resources will be set to "zero" with the exception of natural gas. The amount of natural gas production will be substituted by synthetic gas production and applied to the calculator tool according to Switzerland's possible capabilities.

Cost

The Total Annual Cost, for each of the elements within the graph, is calculated with the following equation:

Total Annual Cost = Investment Cost + Fuel Cost + Operations & Management Costs

- **Fuel Cost:** the cost of all consumed fuels and imported electricity for one year, it accounts of the yearly operating time
- **Operations & Management Cost:** the annual Operation and Maintenance cost
- **Investment Cost:** the annual investment cost for each element. Some elements only include one cost component, e.g. "Transport fuels" has only the Fuel Cost. In this approach, cogeneration systems are represented by a single element in the legend, "Combined Heat\&Power". This avoids calculating the cost allocation to electricity and heat production, which is an advantage in comparison to the approaches based on levelised cost of electricity and heat (SwissENERGYScope, Cost Model, 2012).

The investment cost is calculated for each year (2035 and 2050) by assuming that the complete energy system is entirely replaced during the selected year, taking into account the relative prices and the technology development status (SwissENERGYScope, Cost Model, 2012). The investment cost is based annually on the interest rate with the following equation:

Investment Cost = Total Investment Cost * [i * ((1 + i) ^ n)] / [((1 + i) ^ n) – 1]

- "**i**" is the interest rate
- "**n**" is the technology lifetime in years.

This assumption allows comparing the investment cost of 2011 with those for 2035 and 2050, without having to consider any installation/decommissioning pathway (SwissENERGYScope, Cost Model, 2012).

3.6.2 General Indicators (Main Graph Headings)

This section contains a brief description of the "General Indicators" of the ENERGYScope calculator tool. There are seven General Indicators labelled: Final Energy, Electricity, Renewables, CO2, Waste, Cost and All. Each "indicator" comprises of its own bar graph with color-coded components that can be viewed by yearly, seasonal or monthly totals.

Final Energy

Final energy consumption is the amount of energy that consumers in Switzerland can buy to satisfy the demand of energy services. The waste heat from power generation is also added to the final energy consumption. In the detailed graph, the energy consumption is separated by its components in relation to the electricity (el.) usage (i.e. heat pumps or direct use) and the thermal processes (th.) such as boilers, cogeneration, solar heat and geothermal resources (PROGNOS, 2012). The total amount can be measured in GWh/year or kWh/per person in Switzerland. The estimated population of Switzerland for 2050 is 10 million people (PopulationPyramid, 2019).

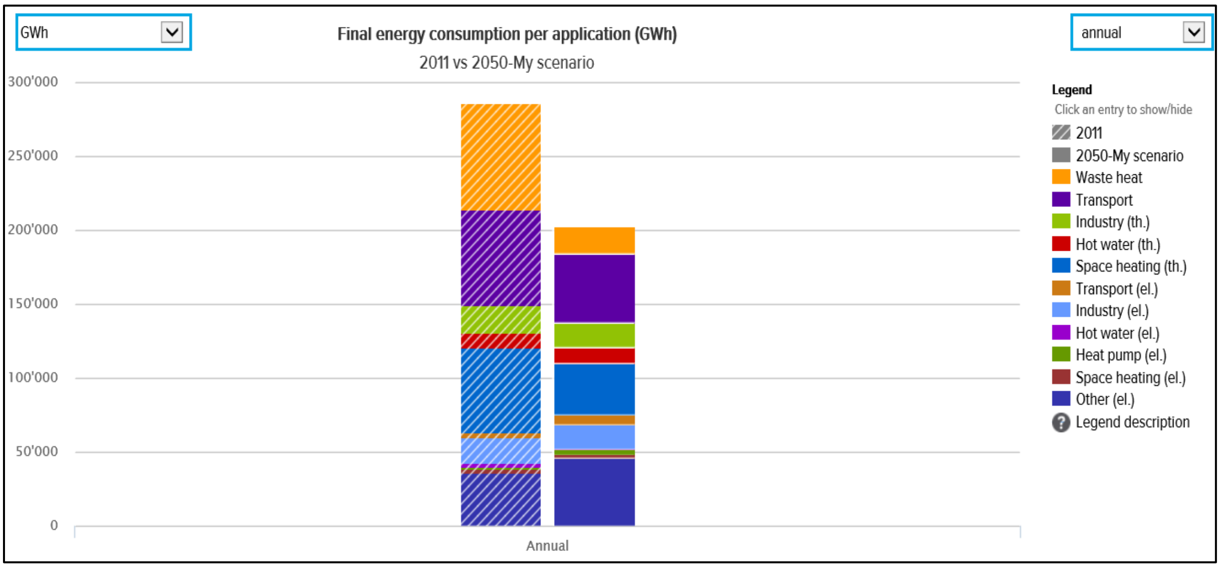

Figure 18: Example of Yearly Final Consumption Graph
(ENERGYScope Calculator, 2012)

Electricity

The electricity General Indicator specifies the annual national electricity demand. It is combined with the yearly electricity deficit (red) and the annual electricity surplus (green). The red part of the bar shows the electricity demand that is covered thanks to imported electricity. The green part represents the electricity that cannot be consumed in Switzerland due to an excess of production. For example, during the summer electricity demand is lower than any other season resulting in a surplus.

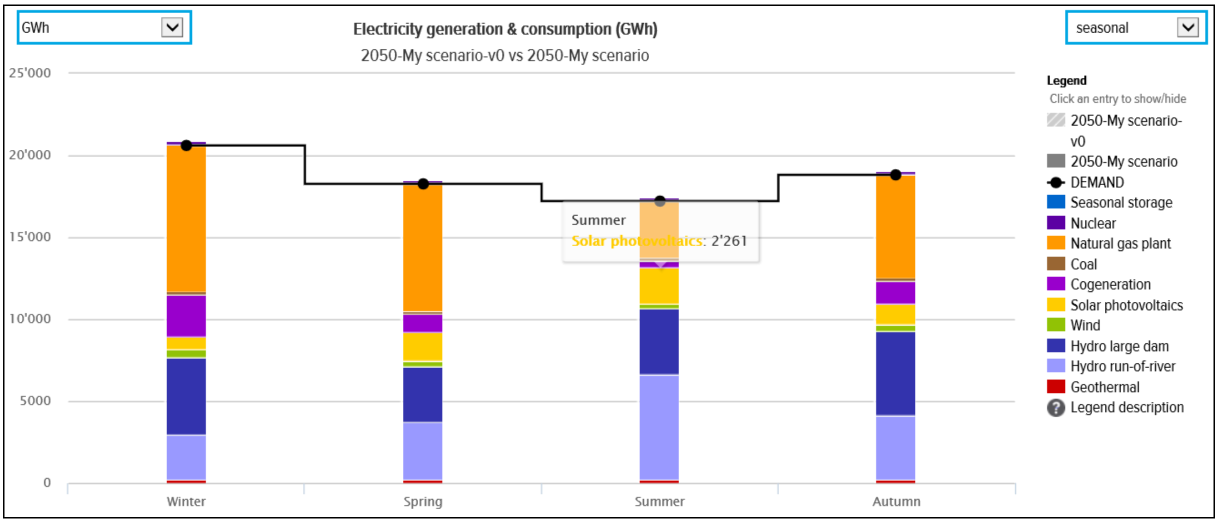

Figure 19: Example of Seasonal Electricity Generation Graph
(ENERGYScope Calculator, 2012)

Renewables and Non-renewable Sources

The Renewable indicator displays the percentage of consumed energy from renewable and non-renewable sources. It provides a breakdown of each component and shows how each specific component contributes to the overall consumption per season. In this example, it can be seen that the energy demand is lower during the summer due to the warmer weather conditions. The quantity of Natural gas is higher during the colder seasons in order to provide heat for housing.

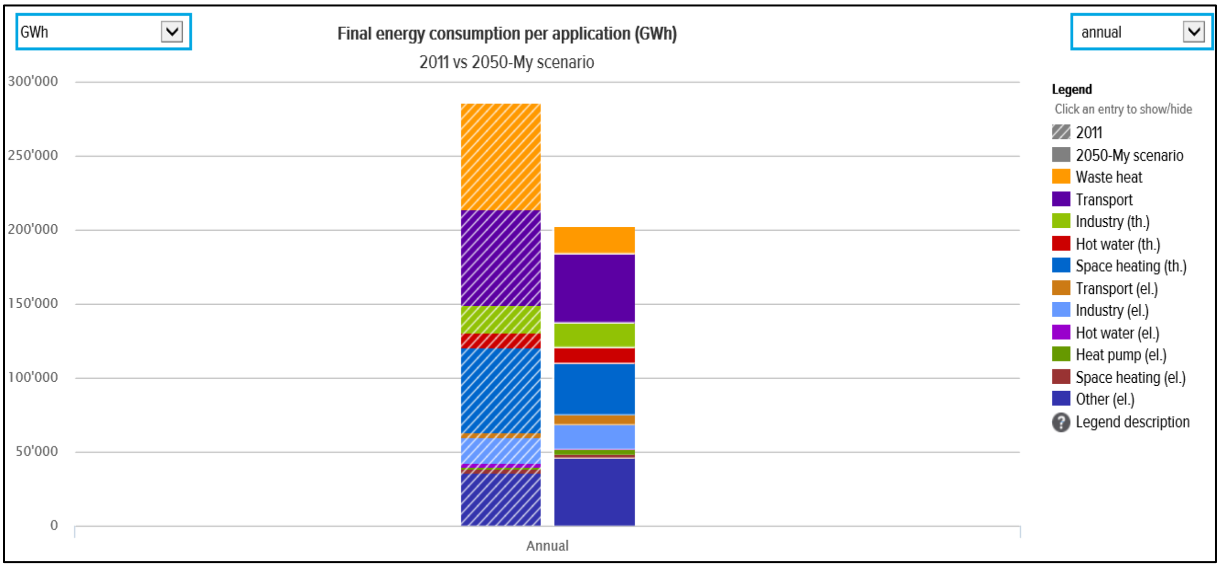

Figure 20: Example of Seasonal Renewable & Non-renewable Sources Graph (EPFL, 2012)

CO2

This indicator reflects the CO2 equivalent emissions of the six main greenhouse gases that are associated with the conversion and consumption of energy (CO2, CH4, N2O, HFCs, PCFs and SF6). This amount of each CO2 equivalent can be displayed in the graph by either thousand-tons/year or kg/person. Switzerland aims to reduce GHG emissions 20% in 2020 relative to 1990 (PROGNOS, 2012).

There is a chance that human activities on earth have contributed to the Greenhouse gas (GHG) emissions, resulting in global warming. A worldwide temperature increase is likely to result in social, economic and environmental damage associated with an increase of extreme weather events, sea level rise and ocean acidification. For Switzerland, the melting of glaciers and permafrost are amongst the most critical direct environmental impacts of global warming, potentially leading to severe socio-economic impacts (PROGNOS, 2012).

Reducing GHG emissions is also important to the economy as a whole. For example, a carbon tax of 60 CHF/ton applies to heating oil and gas, which corresponds to a total annual revenue for the Confederation of about CHF 740 million (PROGNOS, 2012). Future policy measures to mitigate global warming are likely to increase the penalty for exceeding the allowable amount of emissions of greenhouse gases. The penalty has already increased 24 CHF/ton since 2012 (PROGNOS, 2012).

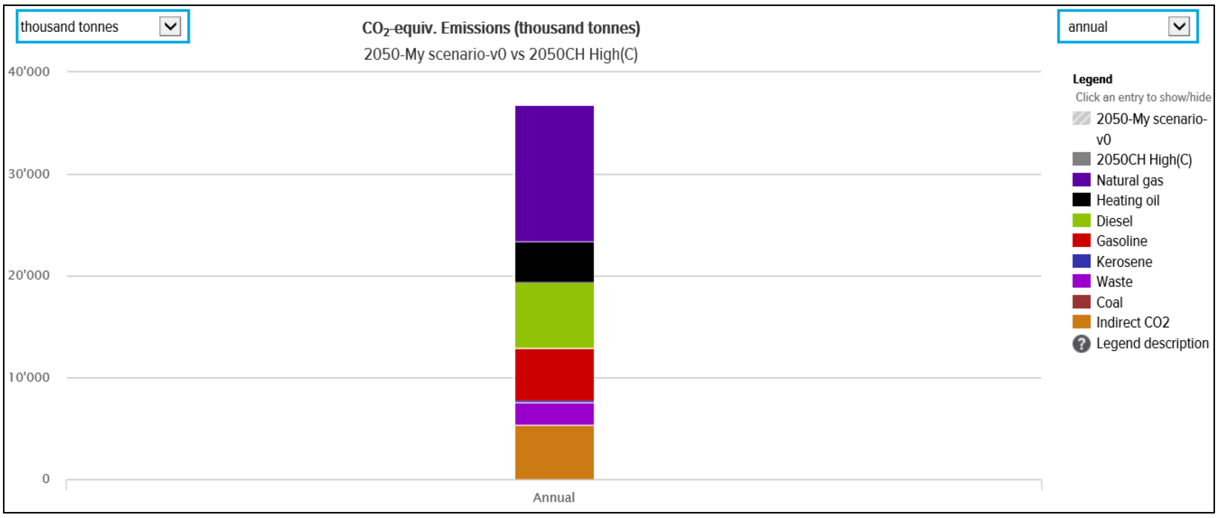

Figure 21: Example of Yearly CO2 Emissions Graph (EPFL, 2012)

Waste

The impact assessment method used for calculating the deposited waste is "ecological scarcity 2006 / total deposited waste". This method takes into account the volume required for storing the generated waste (including the radioactive waste) and the contaminants dumped into the water (river, sea and underground streams). The computation of the deposited waste is based on a life cycle analysis. The amount of the waste is measured in "UBP", which is an abbreviation for "Umweltbelastungspunkte" in German. In English, the unit of measure is "billion Eco points" (PROGNOS, 2012).

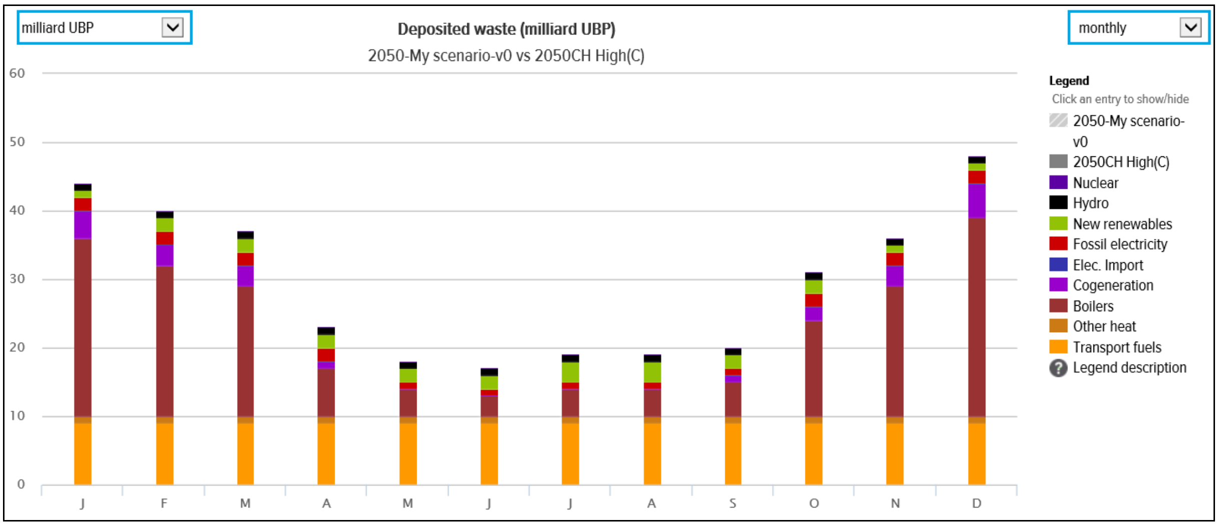

Figure 22: Example of Monthly Waste Graph (EPFL, 2012)

In the graph, the deposited waste is broken down by component and labelled as:

Component	Description of Origin of Waste
Nuclear	Emissions linked to the construction and decommissioning of the nuclear power plants. It also accounts for the emissions related to the nuclear fuel chain.

Hydro	Emissions linked to the construction and decommissioning of hydro power plants (run-of-river and hydro large dam.)
New Renewables	Emissions linked to the construction and decommissioning of wind turbines, photovoltaic panels and geothermal power plants.
Fossil Electricity	It accounts for the operation and construction/decommissioning emissions of gas and coal power plants.
Electricity Imports	The imported electricity also produces emissions. Even though, the emissions occur in the country where the power plants are located, they are accounted for in Switzerland where the electricity is consumed.
Cogeneration	It accounts for the operation and construction/decommissioning emissions of cogeneration systems.
Boilers	It accounts for the operation and construction/decommissioning emissions of boilers.
Other Heat	Emissions linked to the construction and decommissioning of the next systems for heat production or cogeneration: heat pumps, solar thermal panels, direct electric heating systems and geothermal cogeneration systems.
Transport fuels	Emissions linked to the use of fuels in the transport sector (combustion, production and distribution of the fuels are accounted).

Table 9: Description of Origin of Waste (SwissENERGYScope, Deposited Waste, 2012)

Cost

The inputs of the cost sub-model are the “Fuel Prices”, “Investment cost” and “Interest rate” sliders. The extreme values of these three inputs are “1” and “3”, with “1” assuming the lowest value for the costs, and “3” the highest values (SwissENERGYScope, Cost Model, 2012). For this report, these sliders will be set at the average value of “2” in order for simplicity in calculating cost estimations for 2050.

The “Fuel Prices” slider is based off bioethanol and biodiesel and are considered to have the same price evolution as the fuel they substitute (gasoline and diesel respectively). The price for wood in 2035 and 2050 is calculated following the same methodology used for the fossil fuel prices, but the evolution is based on the wood price forecasts in the Prognos Report (Dr. Almut Kirchner, 2012).

The “Investment cost” input determines which of the three levels of specific investment cost is considered. The “Interest rate” slider sets the interest rate. The defined range for the interest rate is 1.73 to 4.70%. It should be noted that these values are based on the observed performances of the electricity production companies in 2012 (Dr. Almut Kirchner, 2012) (SwissENERGYScope, Cost Model, 2012).

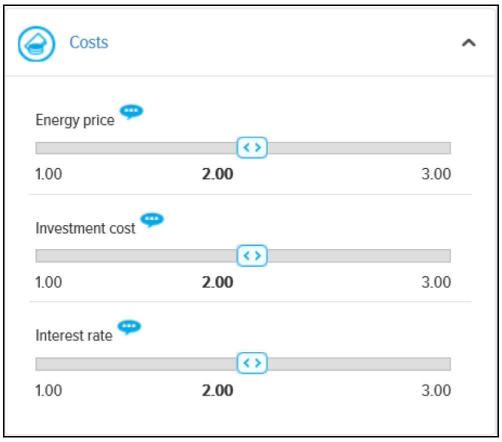

Figure 23: Cost Sliders (SwissENERGYScope, Cost Model, 2012)

Fuel prices: The “Fuel prices” input defines which of the three price levels that are selected for the cost calculation. The following Table 10, shows the production prices or Swiss border prices, if the resource is imported. Taxation is not accounted for in the cost calculations (SwissENERGYScope, Cost Model, 2012).

ctsCHF/kWh$_{fuel}$	2010	2035			2050		
		MIN(1)	MID(2)	MAX(3)	MIN(1)	MID(2)	MAX(3)
Gasoline	8.59 [1][2]	9.18	11.30	14.76	8.55	12.90	16.51
Diesel	8.41 [1][2]	8.99	11.07	14.46	8.38	12.64	16.18
Bioethanol	7.36 [8]	9.18	11.30	14.76	8.55	12.90	16.51
Biodiesel	11.93 [8]	8.99	11.07	14.46	8.38	12.64	16.18
Heating fuel oil	6.54 [1][3]	6.99	8.60	11.24	6.52	9.83	12.58
Kerosene	5.91 [4]	6.32	7.78	10.16	5.89	8.88	11.37
Gas	6.50 [5]	6.15	10.07	13.00	6.62	12.07	15.87
Wood	3.01 [7]	6.82	7.81	8.80	7.41	8.96	10.50
Coal	3.60 [6]	3.76	5.34	7.26	3.68	5.43	6.51
Imported electricity [ctsCHF/kWh$_e$]	15.90 [5]	15.90	24.00	32.10 [7]	15.90	24.75	33.60 [7]

Table 10: Fuel Cost Calculations & 2035, 2050 Estimations (SwissENERGYScope, Cost Model, 2012)

The prices for fossil fuels in 2035 and 2050 are calculated by the following equations, taking into account the 2010 prices and the three evolution paths forecast by the European Commission (EuropeanCommission, 2011).

$$Price_{2035/2050_1} = \frac{Price_{2010} * Price_{EuropeanCommission2035/2050_{Low}}}{Price_{EuropeanCommission2010}}$$

$$Price_{2035/2050_2} = \frac{Price_{2010} * Price_{EuropeanCommission2035/2050_{Ref}}}{Price_{EuropeanCommission2010}}$$

$$Price_{2035/2050_3} = \frac{Price_{2010} * Price_{EuropeanCommission2035/2050_{High}}}{Price_{EuropeanCommission2010}}$$

Figure 24: Price Equations for Cost Slider Calculations (SwissENERGYScope, Cost Model, 2012)

4 Results

This section of the report provides the results achieved through analysis of the literature research. It gives a brief description of each topic, along with data, in the form of tables, charts and graphs. The order of which the topics are presented in this section is relevant because it provides a trail of the thought process. It begins with the Base Case, followed by the Assumptions applied to the results and then ending with the numerical results of the five candidate Scenarios. The Discussion of Results section in Chapter 5 will then provide the reasoning behind which Scenarios were chosen as successful options for detailed analysis.

4.1 Base Case

The table below shows the values of the Base Case. The complete description of the development of the Base Case can be found in the Methodology section of this report. The purpose of this table is to provide a starting point for analysis and show how much Switzerland relies on nuclear, imports and non-renewable energies in order to meet their yearly energy demand.

Base Case	
Total Domestic Energy Production (2019) without Nuclear & Other Non-renewable Energies (GWh/year)	
Solar PV	1,944
Wind	122
Hydro	37,428
Deep Geothermal	0
Biomass	14,722
Other	1,811
Synthetic Gas	0
Total	**56,027**
Total Energy Consumption (2019) minus Total Domestic Energy Production (GWh/year)	
Total Energy Consumption	230,800
Total Domestic Energy Production	-56,027
Total Deficit	**174,773**

Table 11: Base Case Values

4.2 Assumptions of Report

The list of assumptions in **Table 12** below were developed for use with the ENERGYScope Calculator tool. Their application can be found within the Base Case for scenarios two, three and four. The Calculator tool was not used for Scenarios 1 and 5 because those scenarios are only theoretical and do not consist of any number values. The assumptions are separated into two categories. The first "Category A" represents a direct influence according to the scope of the thesis topic: zero values for imports, nuclear, fossil fuels, a focus on the energy efficiency and renewable source calculator parameters. "Category B" represents assumptions based on current conditions and future estimations.

All listed assumptions, except for "Category A: Assumptions #4 and #5" were first applied to the calculator and remained constant throughout all developed scenarios. Assumption #4 and #5 from Category "A" was adjusted to develop different scenario results according to level of efficiency and domestic energy production.

Assumptions Applied to ENERGYScope Calculator Tool	
Category "A": Scope of Thesis Question	
1	"0 GWh/year" of Imported Energy
2	"0 GWh/year" of Nuclear Energy (Swiss Energy Strategy 2050, Measure 3)
3	"0 GWh/year" of Fossil-fuel Energy throughout all sectors
4	"Minimum, Average, Maximum" Energy efficiency of buildings, mobility, industry and appliances (Swiss Energy Strategy 2050, Measure 1)
5	"Average, Maximum GWh/year" of Renewable Energy Sources (Swiss Energy Strategy 2050, Measure 2)
Category "B": Other Assumptions	
6	Population of 10 million people in 2050
7	Natural gas substituted with 100% Synthetic gas from 100% Biomass feedstock
8	29% of population public transport, 71% driving cars, trucks, vans, freight, etc.
9	50% electric vehicles, 30% Synthetic Gas vehicle, 20% Hydrogen vehicles
10	70% District Heating, 30% Distributed Heating
11	Heating Fuels: Combination of Wood, Synthetic gas and Hydrogen
12	100% Biofuels for freight trucks (100% plant based)
13	Cost: average energy price, average investment cost & average interest rate
14	"Zero" Deep Geothermal contributions (earthquake activity)

Table 12: Assumptions Applied to Calculator Tool

4.3 Scenarios

This section provides the key results for the five candidate scenarios, along with a short description of each. The charts, tables and graphs show which scenarios are able to meet their energy demand yearly, seasonally and monthly. It also provides the amount of CO2 emissions and cost of annual maintenance.

4.3.1 Scenario 1: Application of 100% Global Renewable Case Study to Switzerland

The results of the first scenario are taken from a case study conducted by LUT University and the Energy Watch Group. It is titled, “Global Energy System Based On 100% Renewable Energy”, which provides a solution for how the entire world could generate all its energy just from renewable sources. The first figure below shows what a world with 100% renewable energy would look like. It consists of mostly solar PV and wind power.

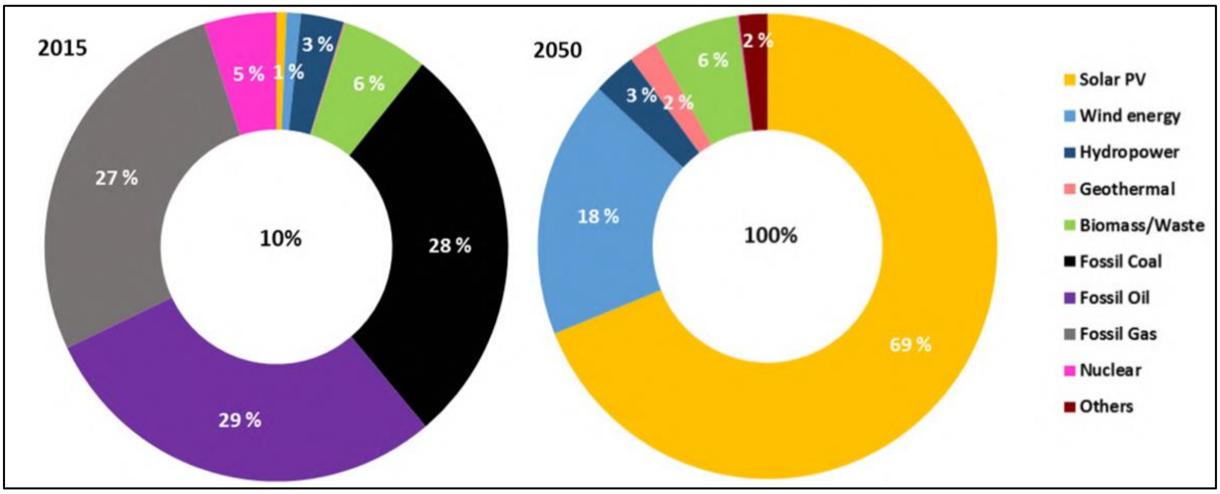

Figure 25: Percentage of Energy Solution (LUT and EWG, 2019)

This table lists some key findings of the case study regarding GHG emissions, jobs creation, policies and cost reductions:

Table of Key Findings of 100% Global Renewable Energy System	
1	Feed-in Tariff laws should be adopted to enable investments (under 40 MW) from decentralised actors, such as small and medium enterprises, cooperatives, communities, farmers and citizens. Tendering procedures for large-scale investors should only be applied for utility-scale capacities above 40 MW.
2	Annual global greenhouse gas (GHG) emissions in the energy sector decline steadily through the transition from approximately 30 GtCO2eq in 2015 to zero by 2050.
3	A 100% renewable power system will employ 35 million people and solar PV emerges as the major job creating industry, employing more than 22 million by 2050, followed by battery, biomass, hydro and wind industries. See the graph on the right in **Figure 26** below.

4	A 100% renewable power system will employ 35 million people and solar PV emerges as the major job creating industry, employing more than 22 million by 2050, followed by battery, biomass, hydro and wind industries.
5	The approximate 9 million jobs in the global coal industry of 2015 will be reduced to nearly zero by 2050 and will be overcompensated by more than 15 million new jobs in the renewable energy sector.
6	Cost reductions for regions: Middle East and North Africa (-31%), North America (-22%), South America (-34%), and Europe (-15%). The levelised cost of electricity decreases substantially from around 78 €/MWh in 2015 to around 53 €/MWh by 2050, while the levelised cost of heat increases from around 39 €/MWh in 2015 to around 49 €/MWh by 2050.
7	In contrast to popular claims, a deep decarbonisation of the power and heat sectors is possible by 2030. The transport sector will lag behind, with a massive decline of greenhouse gas emissions from 2030 to 2050.
8	Annual global greenhouse gas (GHG) emissions in the energy sector decline steadily through the transition from approximately 30 GtCO2eq in 2015 to zero by 2050.

Table 13: Key Findings (LUT and EWG, 2019)

The graph on the left in **Figure 26** shows the decrease in overall GHG emissions by sector. The graph on the right shows how job employment will transition from the fossil fuel industry to the renewable energy industry. The job transition is estimated to increase the total amount of jobs available in 2050, compared to the current situation of 2020.

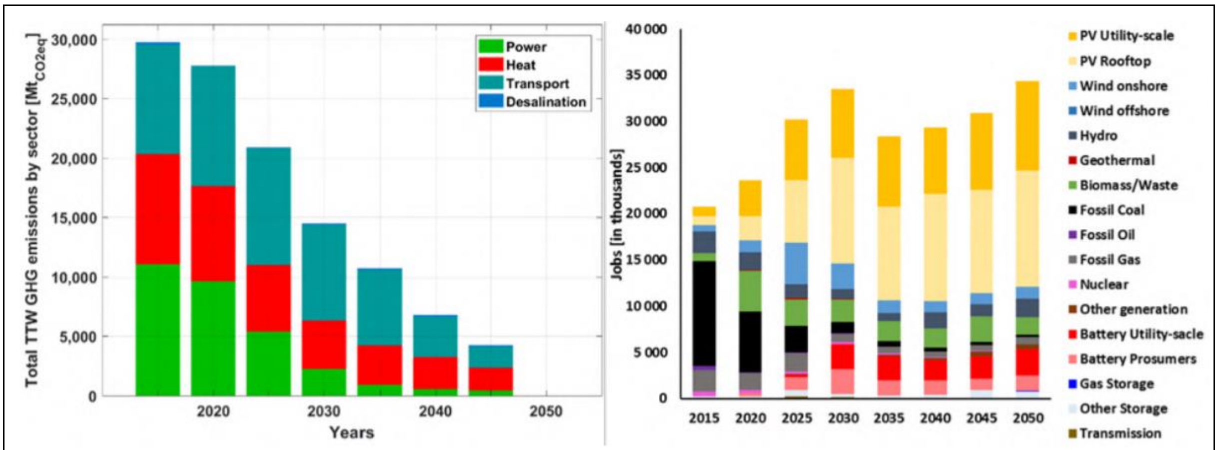

Figure 26: Greenhous Gas Emissions & Job Creation (LUT and EWG, 2019)

Figure 27 below shows how the entire energy demand will switch from using mostly fossil fuels in 2015, to using mostly electricity in 2050. The overall energy demand increases from about 125,000 TWh in 2015, to approximately 150,000 TWh in 2050. This is due to the estimated population growth of about 7.2 billion in 2015, to 9.7 billion in 2050 (LUT and EWG, 2019). The final energy demand is “expected to grow by about 1.8% annually, driven by energy services for higher level of living standard, and is accompanied by massive energy efficiency gains” (LUT and EWG, 2019).

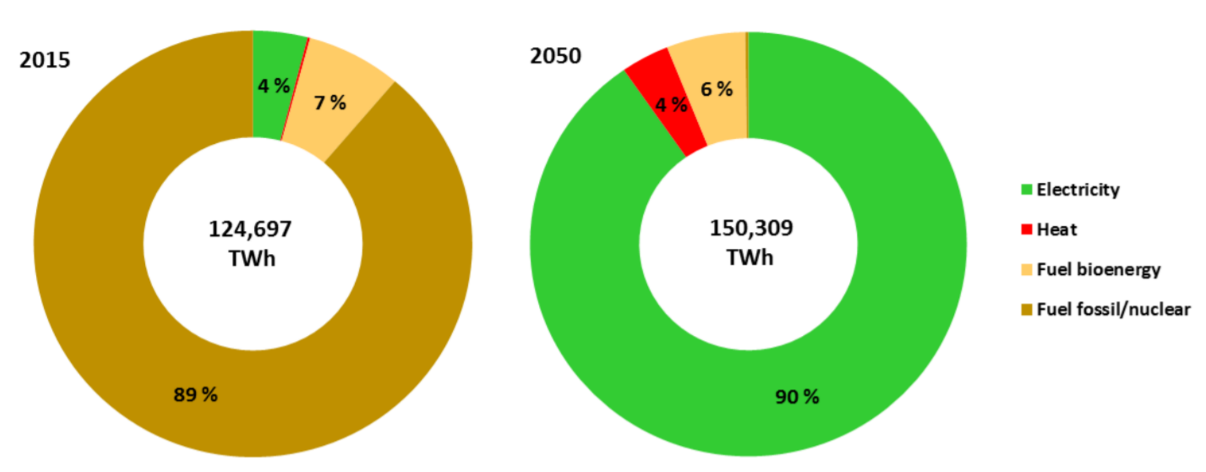

Figure 27: Demand Comparison (LUT and EWG, 2019)

Estimations of the Differences in Energy Supply by Region	
1	The energy transition will have some key regional renewable energy generation differences. Almost all Sun Belt countries will use solar PV as their primary source of electricity. See **Figure 28** below.
2	South Asia has a world record share of 95% solar PV electricity generation by 2050 in its cost-effective generation mix.
3	In Eurasia, onshore wind dominates electricity generation, with the highest shares worldwide. Onshore wind ranges from 61% in 2025 to 47% in 2050, with solar PV generation only gradually increasing towards 2050.
4	Few regions have a diversified mix of renewables with solar PV, wind energy, and hydropower in their energy supply, such as the Nordic region, Western Eurasia, Central China, Chile, and New Zealand.).
5	By 2025, North America is set to have approximately 25% of the global wind energy provision. Towards 2050, the costs of electricity provision in North America can be reduced by more than a third. The transition will be accompanied by an increase in jobs from around 1.8 million to about 2.7 million by 2050.
6	The diverse range of energy systems is induced by locally available resources, which enhances energy security around the world; this could lead to a more peaceful and prosperous global community.

Table 14: Key Findings of Energy Supply by Region (LUT and EWG, 2019)

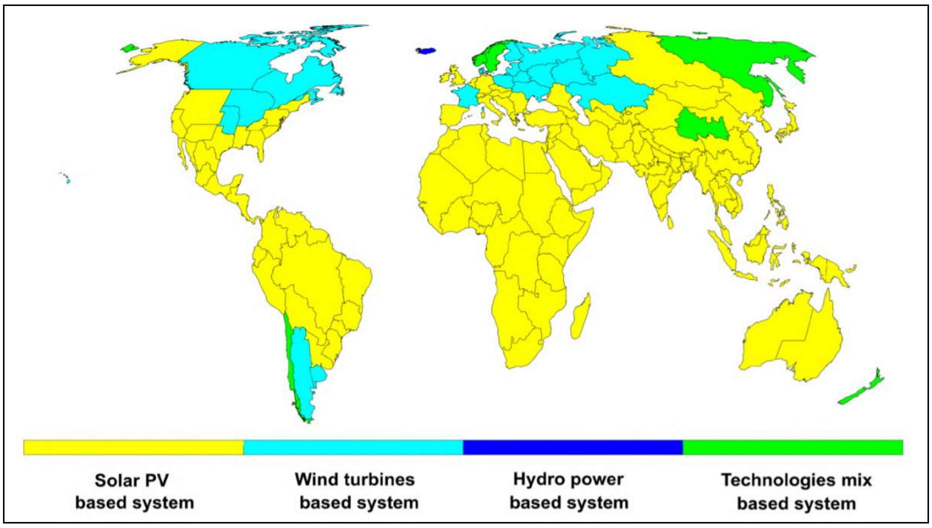

Figure 28: Map of Primary Energy Source Contributions (LUT and EWG, 2019)

4.3.2 Scenario 2: Maximum Renewable Energy Output with Maximum Demand Efficiency (Max Supply / Min Demand)

The results of Scenario 2 were achieved by applying the Base Case and previously mentioned assumptions. The total maximum and achievable energy supply was combined with the lowest estimation of energy demand in 2050. As a result, Scenario 2 can be thought of as the “best case scenario”. The results for total energy demand, renewable energy sources, electricity supply (seasonal), CO2 emissions, amount of waste and annual maintenance costs can be seen in the following figures below.

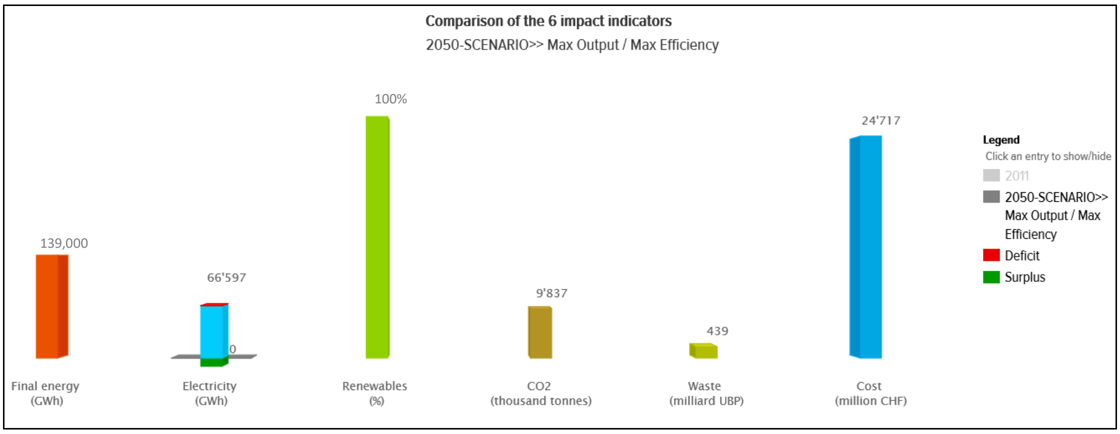

Figure 29: Scenario 2 All General Indicators

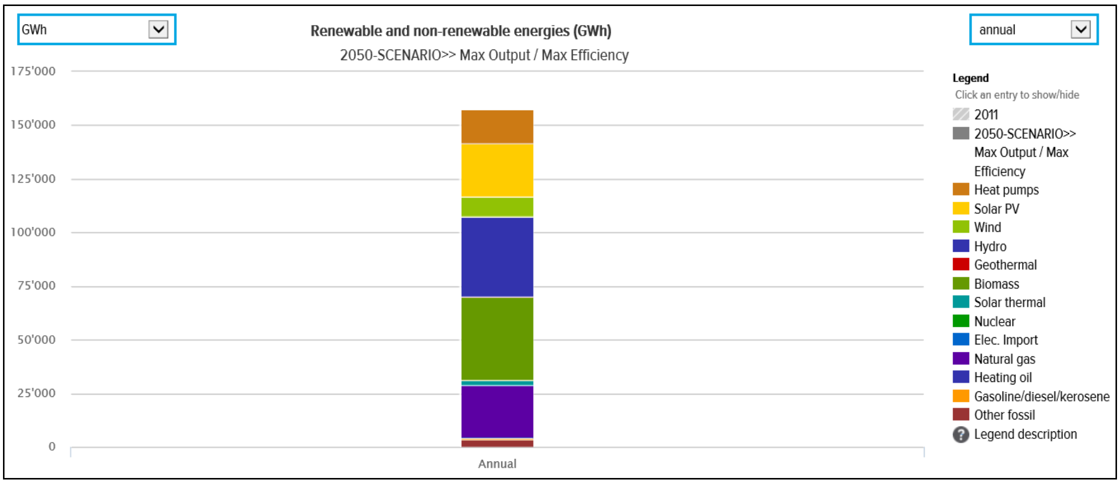

Figure 30: Scenario 2 Renewable Energy

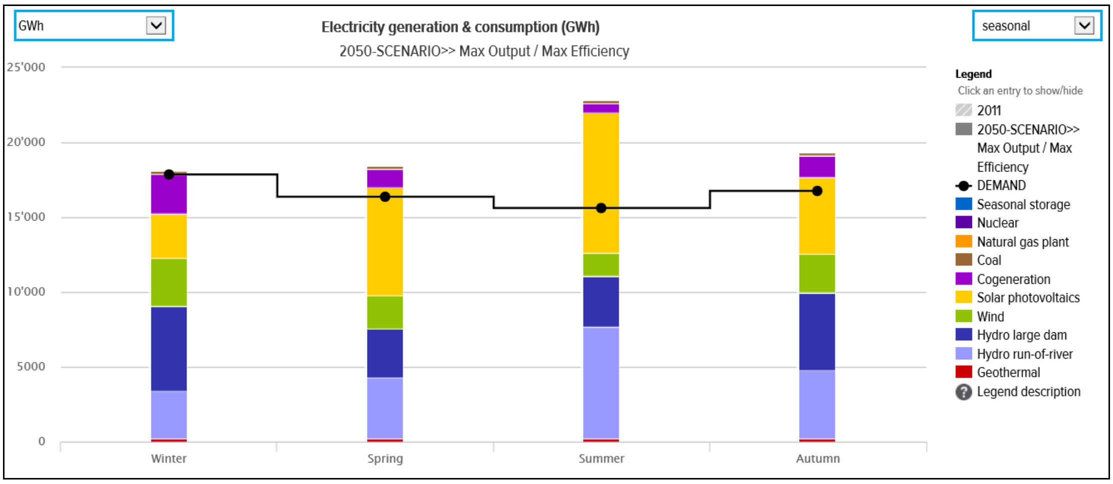

Figure 31: Scenario 2 Seasonal Electricity Generation

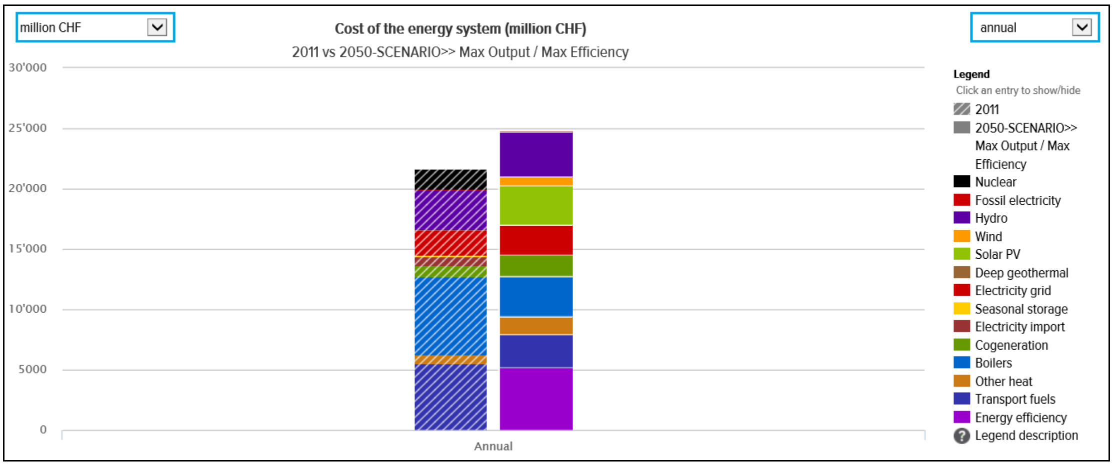

Figure 32: Scenario 2 Annual Maintenance Cost of Energy System

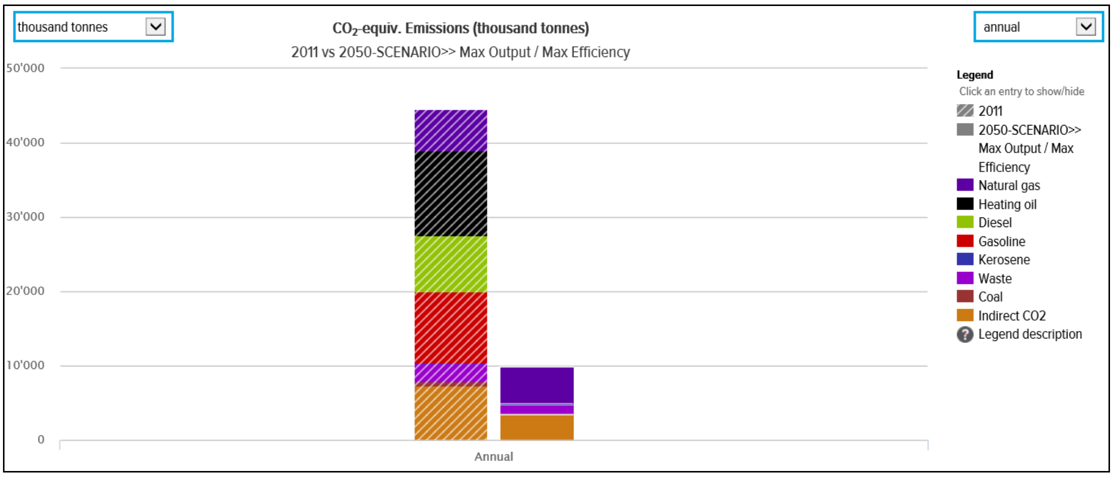

Figure 33: Scenario 2 CO2 Emissions Compaired to 2011

4.3.3 Scenario 3: Maximum Renewable Energy Output with Minimum Demand Efficiency (Max Supply / Max Demand)

The results of Scenario 3 were achieved the same way as Scenario 2, by first applying the Base Case and previously mentioned assumptions. The total maximum and achievable energy supply was combined with the highest estimation of energy demand in 2050. This scenario still applies the maximum energy output capacity of Switzerland but the level of energy demand efficiency is adjusted to the highest level allowed by the ENERGYScope Calculator. The results for total energy demand, electricity supply, CO2 emissions, waste and annual maintenance costs, can be seen in the following figures below.

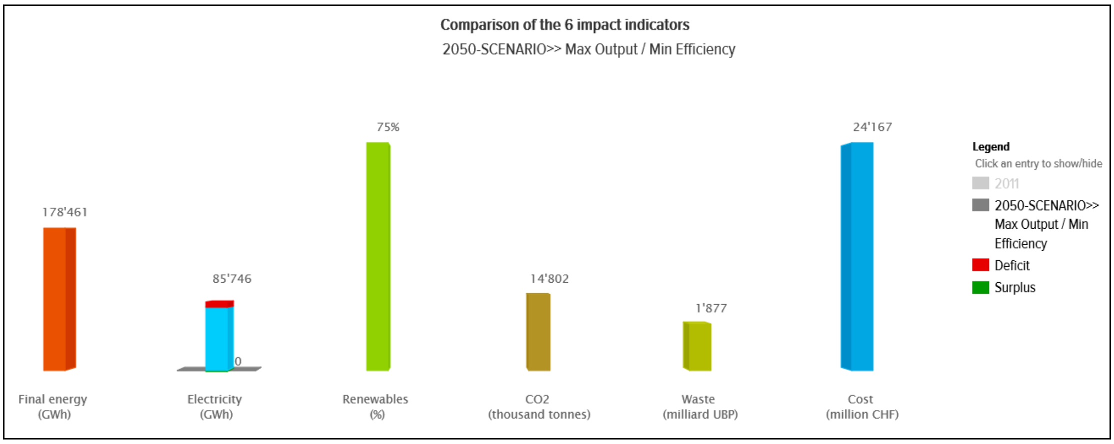

Figure 34: Scenario 3 All General Indicators

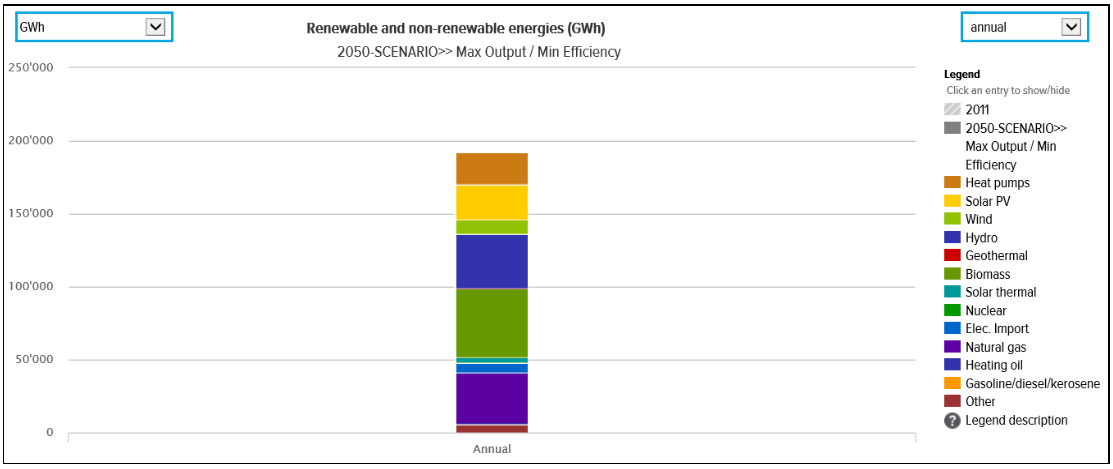

Figure 35: Scenario 3 Renewable Energy

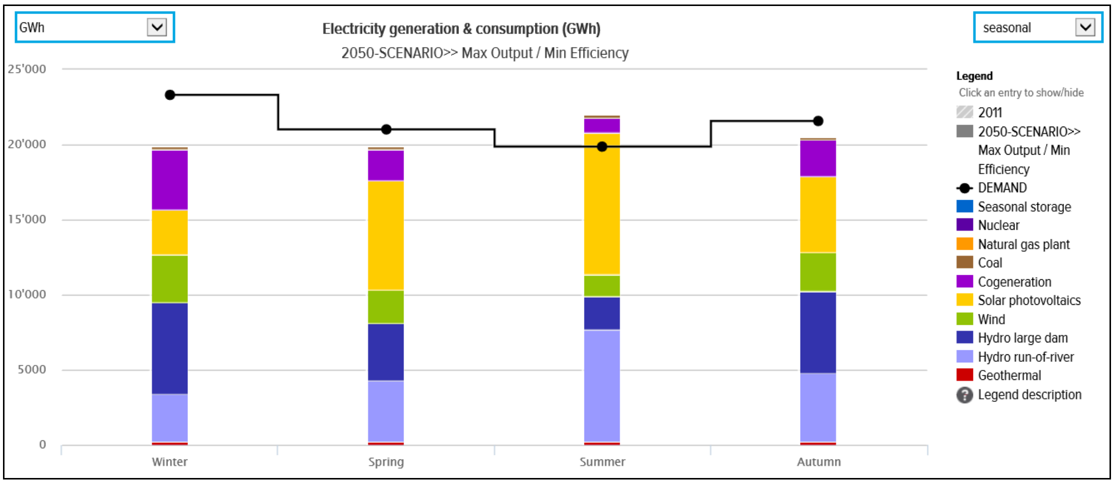

Figure 36: Scenario 3 Seasonal Electricity Generation

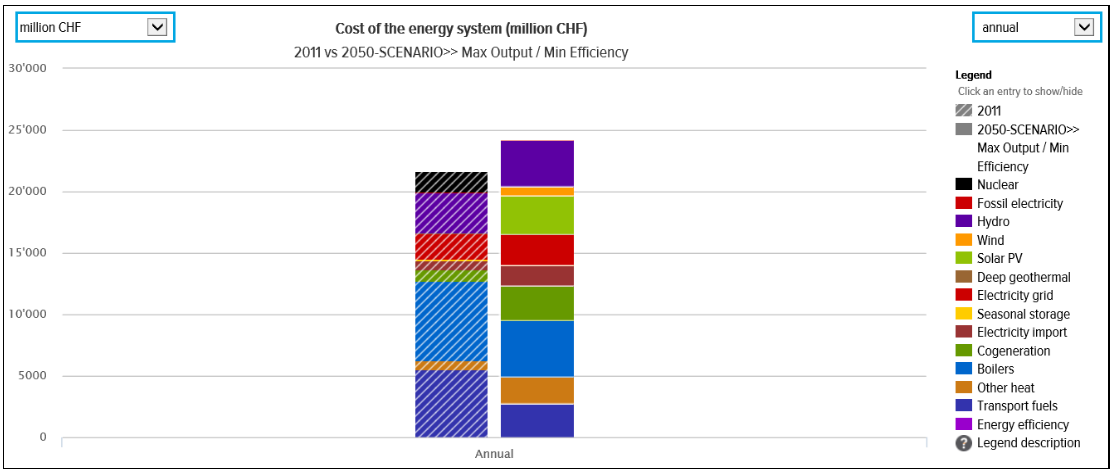

Figure 37: Scenario 3 Annual Maintenance Cost of Energy System

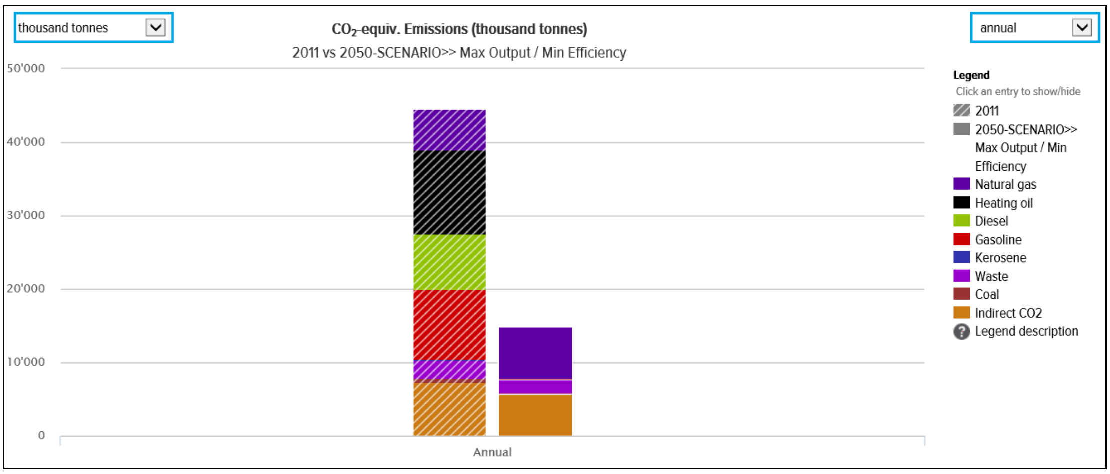

Figure 38: Scenario 3 CO2 Emissions Compared to 2011

4.3.4 Scenario 4: Average Renewable Energy Output with Average Demand Efficiency (Average Supply / Average Demand)

The results of Scenario 4 were also achieved in the same manner as Scenario 2 and 3, by first applying the Base Case and previously mentioned assumptions. Adjustments were made to both energy production and demand efficiency to form the average results. However, hydropower contributions were not changed because they are a "staple" in the Swiss energy supply. The results for total energy demand, electricity supply, CO2 emissions, waste and annual maintenance, costs can be seen below.

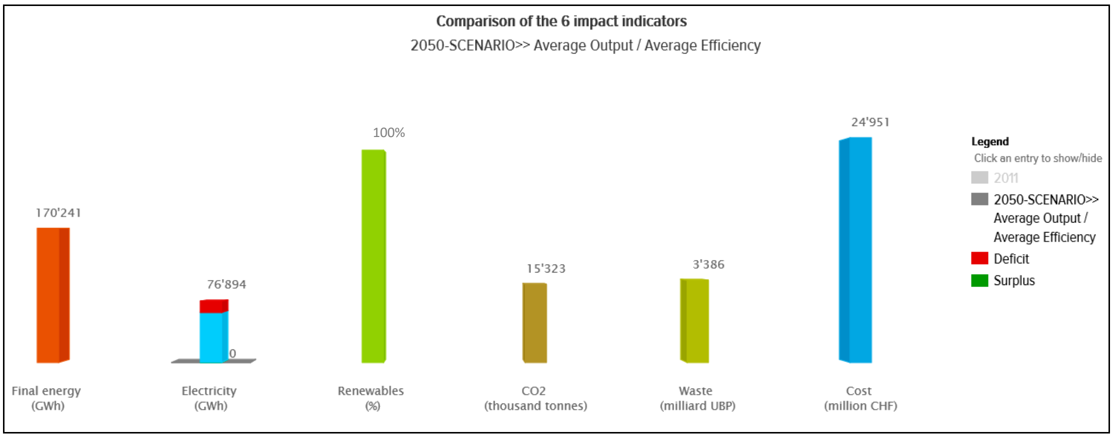

Figure 39: Scenario 4 All General Indicators

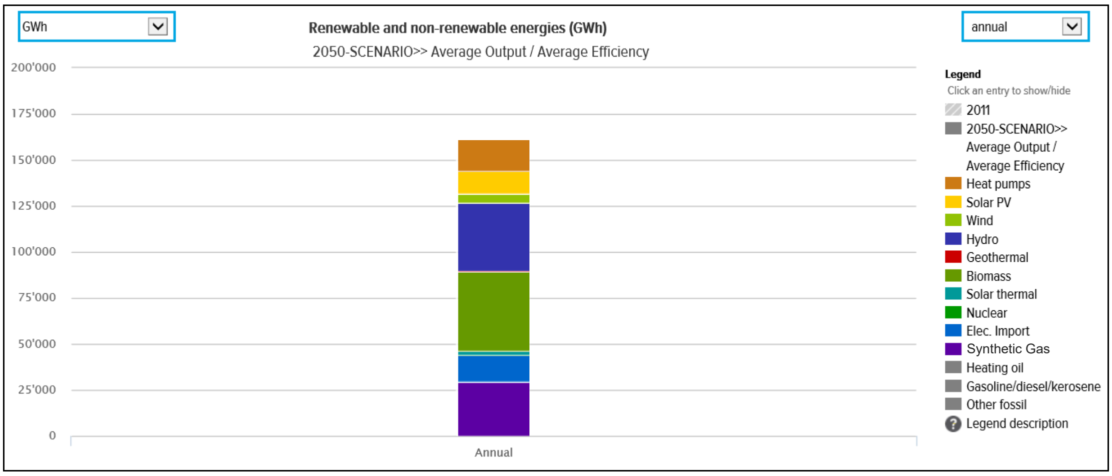

Figure 40: Scenario 4 Renewable Energy

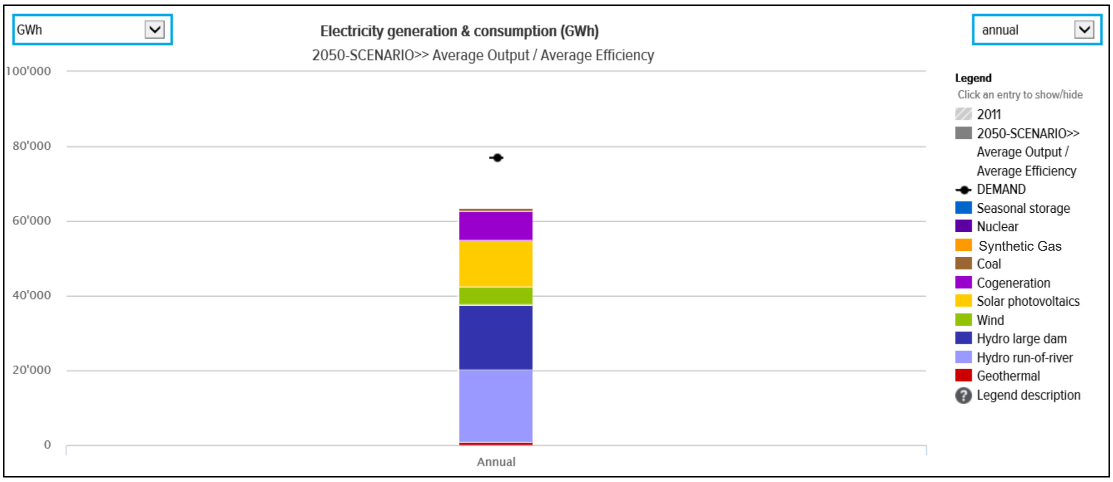

Figure 41: Scenario 4 Seasonal Electricity Generation

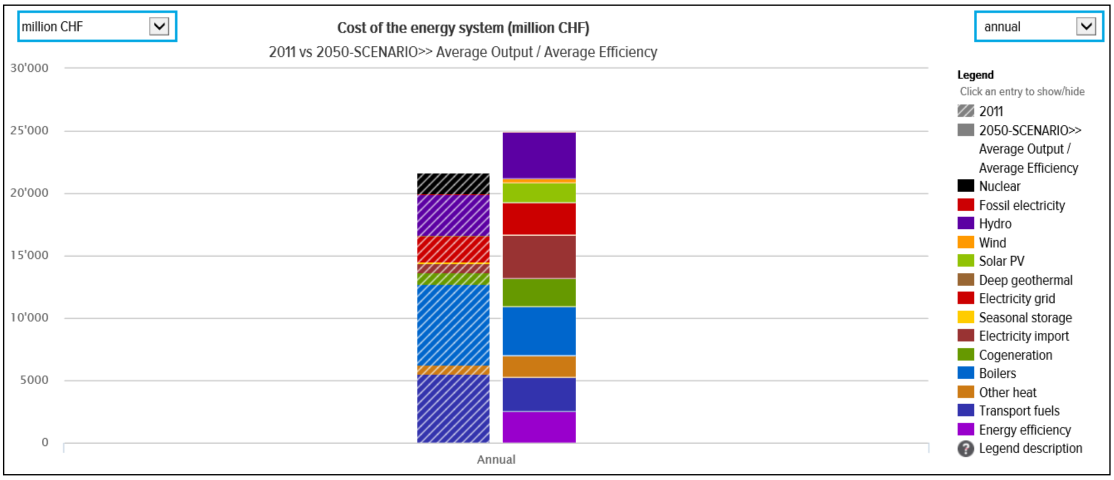

Figure 42: Scenario 4 Annual Maintenance Cost of Energy System Compared to 2011

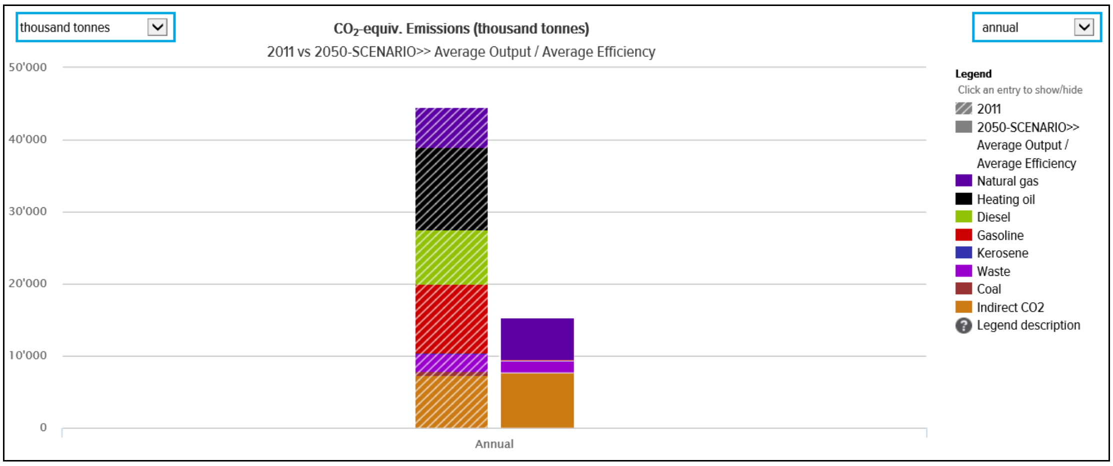

Figure 43: Scenario 4 CO2 Emissions Compared to 2011

4.3.5 Scenario 5: Technology Advancement

There are no numerical values for this results section. This is because the results of Scenario 5 are based off the assumption that, as time goes on, there will be improvements and advancements in technology. Therefore, these values are currently unknown. The world's technology is moving at an exponential pace and it is only a matter of time before a technological breakthrough is made that has a big impact on the energy industry.

Further explanation and reasoning will be discussed later in Section **5.2.4 Scenario 5: Technology Advancement Combined with Scenario 2**.

5 Discussion of Results and Conclusion of Report

This section contains a description of each of the five scenario results and how they were achieved. It begins with describing each of the key renewable energy components and their maximum outputs. It also describes what it would take to implement these maximum outputs and how they can be applied to the five scenarios.

5.1 How the results were achieved

The following section contains a list of components that had the biggest influence on the scenario results and how they were achieved. The components concerning the supply of renewable energy indicate the potential values for the maximum capacity of solar, wind, hydro, biomass and synthetic gas. The components regarding energy demand specify the range of possible efficiencies for average building demand, industry intensity, appliance's consumption and lighting consumption. For more information regarding the efficiency parameters of demand, refer to Section **3.6.1 Input Parameters** of the Literature Review.

5.1.1 Solar PV

The maximum output estimated by the Prognos Report (2012) and the ENERGYScope Calculator (2012) tool is 25 GW, which would produce approximately 25,000 GWh/year (PROGNOS, 2012). This amount assumes that 40% of all capable roofing within Switzerland is covered by solar panels with a 20% panel efficiency. This quantity of energy would make up for about 11% of the 230,800 GWh of total final energy consumed in 2019. However, the SFOE believes the number of installations and solar output could be much higher.

In September 2018, the SFOE announced that they estimate the potential for solar energy coming from roofing to be around 50,000 GWh/year. To calculate this potential they considered only roofs with an area of at least 10 m2 and "good annual radiation" (SFOE, 2019). Once the quantity of available surface area was defined, the energy output was calculated using a "realistic coverage with 70% photovoltaic modules" (SFOE, 2019). This would double the previously mentioned energy capacity and provide approximately 22% of the 2019 total energy demand. However, the SFOE did not stop there with their calculations.

They then considered how much potential energy could be extracted from adding solar panels to the facades of buildings. It was determined that another 17,000 GWh/year of energy could be available. This estimation considers a total "realistic" coverage of 45-65% of every facade with: at least 20 m2 of surface area, that lies within an average range of "good to excellent radiation" and which also has a specific minimum distance from nationally protected Swiss settlements (ISOS)" (SFOE, 2019). Therefore, the complete total solar energy potential of Swiss buildings equates to approximately 67,000 GWh/year.

This amount would be able to cover Switzerland's entire 2019 electricity demand of 57,647 GWh/year, with only using solar power. It would account for about 29% of 2019's total final energy consumption. However, it does not take into consideration the possibility of installing large solar farms in the future. If these were accepted by the country as a solution, it could raise the solar energy potential even higher. Nevertheless, this could be challenging because of the lack of available land due to the small country size of Switzerland. However, even smaller sized solar panel farms would help towards meeting the country's demand and as the efficiency of solar panels continue to increase, the output will also increase. **Figure 44** below shows the steady increase in overall efficiency depending on the type of technology applied. Crystalline Silicon cells is the category found most common amongst standard solar PV systems. Almost 90% of the world's photovoltaics today are based on some variation of Silicon (NREL, 2018).

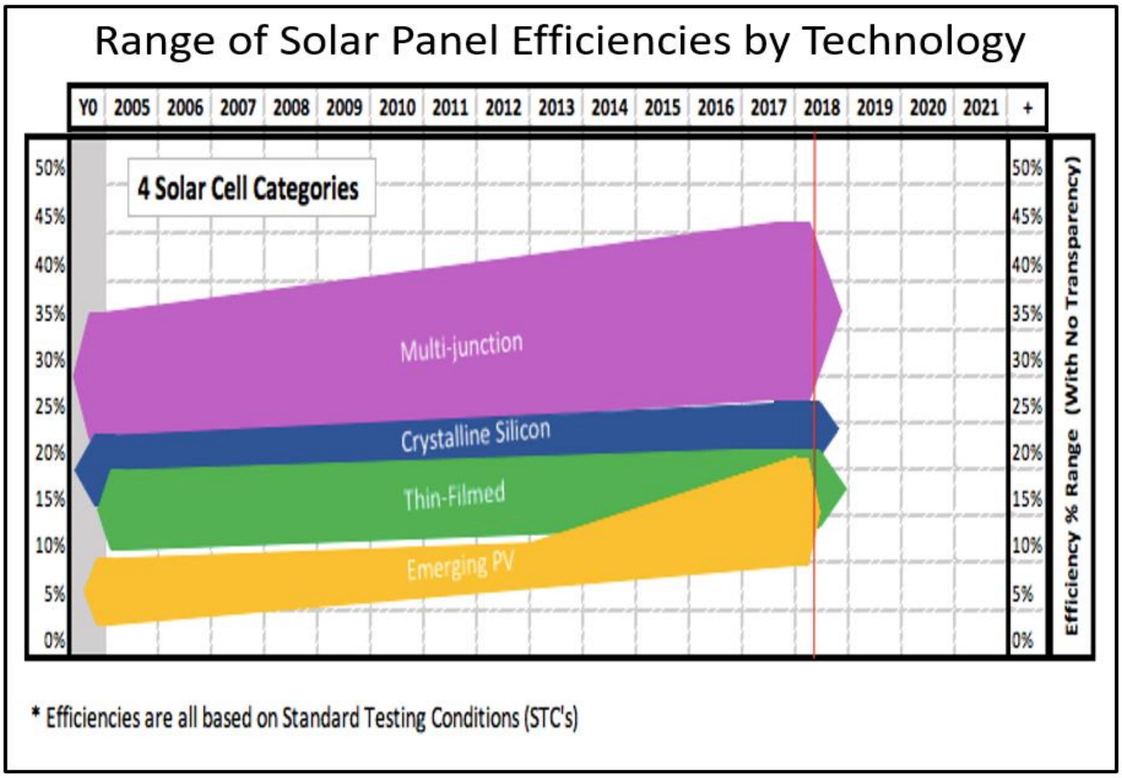

Figure 44: Range of Solar Panel Efficiencies by Category
(Figure Data from (NREL N. R., 2017))

The ability to achieve 67,000 GWh/year from solar power would be a major improvement. However, the ENERGYScope calculator does not allow for a higher input than 25,000 GWh/year. Since this report uses the calculator tool to develop its scenarios, the **25,000 GWh/year** will be used as the maximum output for solar power. However, these statements from the SFOE provide great evidence to support the idea that solar power can absolutely contribute as a major energy source.

5.1.2 Wind

According to the book "Kraftwerk Schweiz" by Anton Gunzinger, the maximum wind capacity potential for Switzerland in 2050 is 10,000 GWh/year (Gunzinger, 2017). This amount is also supported by multiple other sources as a realistic goal. Achieving this would be a major upgrade from the current situation of only about 122 GWh/year. To produce this amount of energy would require approximately .54% (or 223 km2) of Swiss surface area and would need to host 185 wind parks, with 5 to 10 turbines each (ENERGYScope, 2012). This is approximately equivalent to the size of the canton of Zug, who is one of the smallest cantons with 239 km2 (See **Figure 45** below) (Wikipedia, 2019). However, these wind parks would have to be spread out all over Switzerland to avoid coming too close to residential housing and in areas with the best wind conditions. One example of a working system with similar conditions is the German state of Rhineland-Palatinate who already have about 1,200 wind turbines installed that produce 6,000 GWh/year. Even though, they are roughly half the size of Switzerland and have a slightly higher population density, they are able to prove that a significant amount of wind power can be generated in small-populated areas (SwissEnergy, 2019).

The scenario results of this report applied the **10,000 GWh/year** of energy as the maximum capacity of wind power able to be generated in Switzerland, by the year 2050.

Figure 45: Map of Swiss Cantons (Wikipedia, 2019)

5.1.3 Hydropower

Hydropower plays an important role in the Swiss electricity supply and has been the country's most reliable source of renewable energy for years. The Swiss Energy Strategy 2050 is counting on hydropower to at least maintain its stability while it and other renewable sources continue to improve. However, the current yearly amount of 37,500 GWh is already close to the possible max capacity that Switzerland would be able to produce. This is due to a few factors such as the electricity market, available land for expansion and the established environmental protection policies.

The 650 or so hydropower stations are going through a time of uncertainty and according to Barry, et al., "the current mismatch between low market prices and high production costs is perceived as the most pressing challenge for Swiss HP" (Barry, et al., 2015). Adding to these costs is the need to refurbish and update the power plants. Furthermore, the Water Protection Act of 1992 puts more pressure on the hydropower industry by declaring that, with every refurbishment or concession, there must also be an increase of "residual water (rivers, streams, wetlands, fish, etc.)" (Barry, et al., 2015). This in turn, limits the amount of available water capable to produce energy. There is 23 such concessions coming up within the next 30 years (See **Figure 46** below) (Axpo, 2018). As a result, the SVP estimates a decrease of 2,280 GWh/year in 2050 compared to 2019.

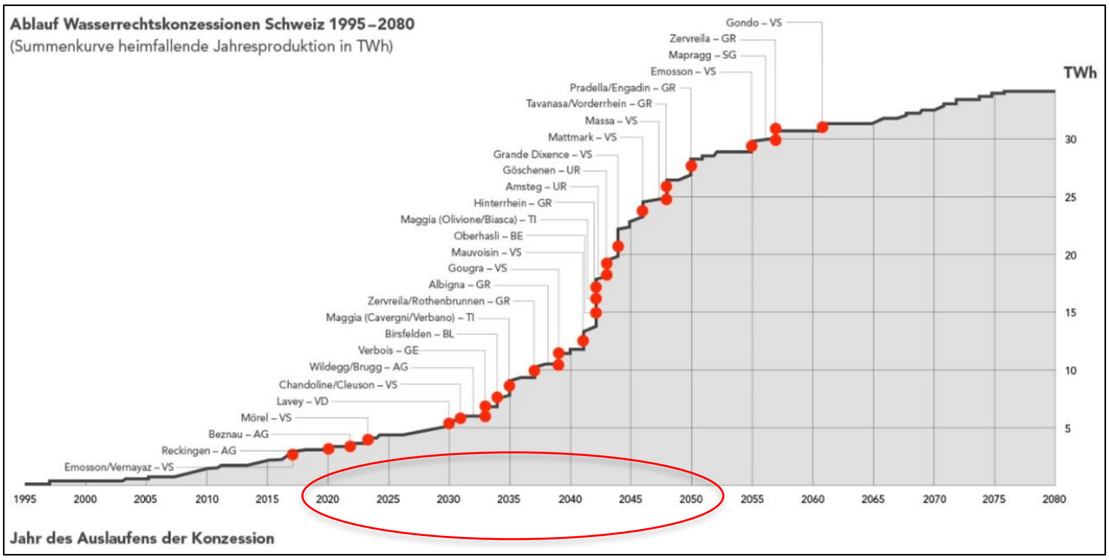

Figure 46: Hydropower Concessions (Axpo, 2018)

Even though, the total productivity of the hydropower sector is predicted to decrease by the year 2050, it is still predicted to have a high contribution to Swiss renewable energy for the next 30 years. Therefore, this report still applies the maximum capacity of around **37,500 GWh/year**, estimated by the ENERGYScope calculator and the International Energy Agency (IEA, Technology Roadmap Hydropower, 2012).

5.1.4 Geothermal

The amount of deep geothermal energy applied to this report is **zero GWh/year**. This is because it was discontinued years ago due to the seismic activity caused by deep drilling (Katharina Link, et al., 2015). However, it should be considered in the future because deep geothermal output is relatively consistent all year long in producing heat energy. The heat below the surface of the earth does not fluctuate drastically during seasonal changes and could provide a reliable amount of energy (ENERGYScope Calculator, 2012). In 2015 the SFOE had set goals for 2050 of 550 MW using deep geothermal, but that has been currently discontinued (seismic activity) (Katharina Link, et al., 2015).

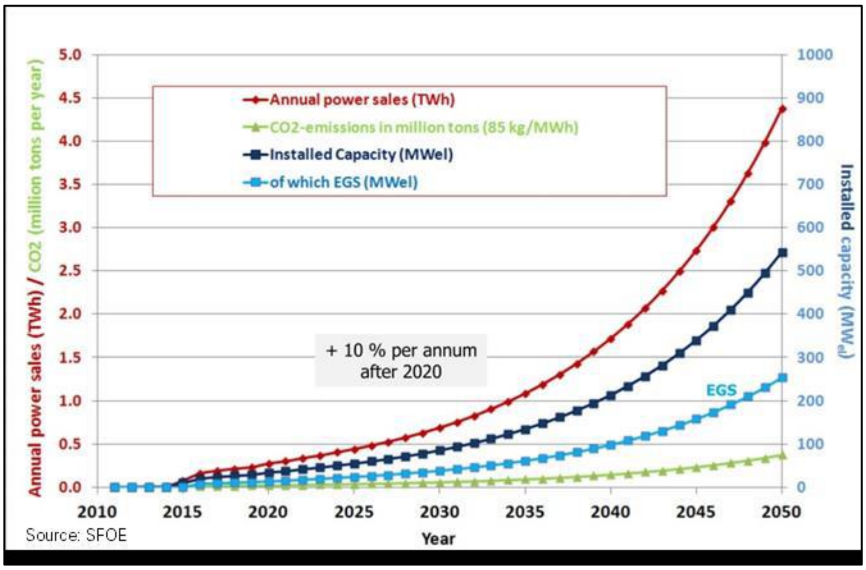

Figure 47: Geothermal Estimations for 2050 (Katharina Link, et al., 2015)

Heat pumps, however, are considered an important part of the Swiss energy revolution. The reason for this is there is an abundance of renewable energy in the ground, water and air. Modern heat pumps make use of this energy using three types of heat pumps:

- Brine-water heat pump: A probe positioned at a depth of 50 to 300 metres draws the heat from the ground.
- Water-water heat pumps: make use of heat from groundwater or surface water.
- Air heat pumps: these pumps draw heat from the surrounding air and do not require any drilling. (Lövold, 2018)

According to FWS statistics, 19, 995 heat pumps were sold in Switzerland in 2017 (FWS, 2019). This amount is predicted to grow even larger by 2050 because Switzerland's revised Energy Act and partially revised CO2-Act contain measures regarding geothermal energy for direct use and power generation (Link and Siddiqi, 2019). According to a report by IEA Geothermal, the "theoretical potential for geothermal is considered very large and realistic estimates of the technical and economic potential (with support mechanisms) is limited to between 1 and 20, 000 GWh/year", along with heat from co-generation (Link and Siddiqi, 2019).

Therefore, for this report will consider **20,000 GWh/year** as the maximum amount of energy generated from geothermal heat pumps.

5.1.5 Biomass

An analysis was conducted in 2017 by the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) and the Swiss Competence Center for Energy Research-Biomass for Swiss Energy Transition (SCCER-BIOSWEET). The purpose of this analysis was to determine the maximum potential of biomass as a renewable solution in Switzerland. They took into account ten different forms of biomass (wood, waste wood, manure, etc.) and determined for each source the theoretical, realistic and sustainable potential. According to their calculations, the total maximum theoretical potential of Swiss biomass is 58,000 GWh/year, of which mainly consists of 30,000 GWh/year from forest wood and 13,600 GWh/year from manure (Oliver Thees, et. al, 2017). This would be about four times higher than the amount being used today.

The current amount of energy produced in Switzerland from biomass consists of about 14,722 GWh/year with an additional amount of around 12,222 GWh/year for harvest (Oliver Thees, et. al, 2017). This amount of energy potential consists mostly of 6,667 GWh/year of manure and 2,500 GWh/year of forest wood (Oliver Thees, 2017). These additional quantities could be added to the current supply of biomass but they are not used because of the current ecological and economical-technical restrictions (Oliver Thees, 2017).

However, of the theoretical maximum biomass energy of 58,000 GWh/year, approximately 27,000 GWh/year of this amount "appears to be achievable from the locally sustainable resources available" (Oliver Thees, et. al, 2017). This total would consist of 13,900 GWh/year of woody biomass and 13,100 GWh/year of non-woody biomass (Oliver Thees, et. al, 2017). For further details of each biomass category, please refer to the appendix section of this report.

The scenario results produced from the ENERGYScope calculator reflects this range of values. It uses the **58,000 GWh/year** as the absolute maximum but strived to keep the proposed scenario results closer to the realistic value of **27,000 GWh/year**.

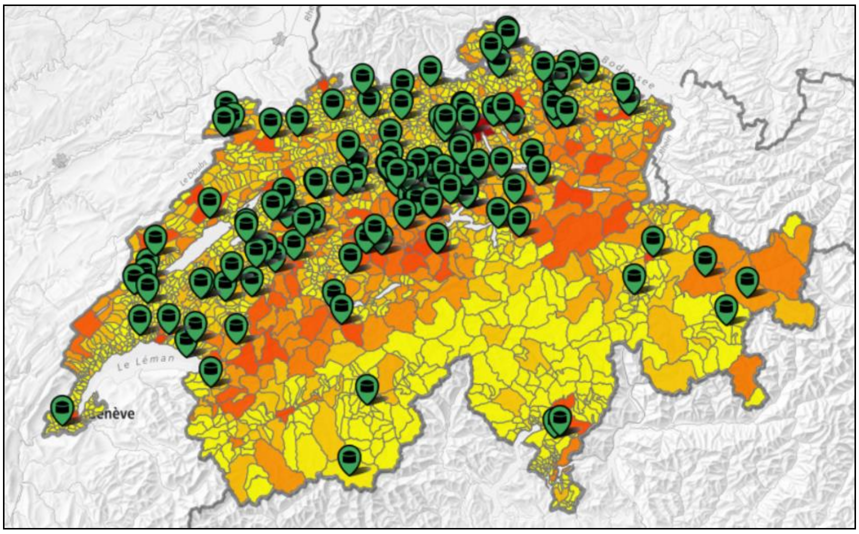

Figure 48: Current & Potential Biomass Plant Locations (Oliver Thees, et. al, 2017)

5.1.6 Synthetic Gas

As of July 2019, the global production of synthetic fuel is only about 240,000 barrels per day or 13.87 million m3/year (Synthetic Fuel, 2019). This is very small in comparison to the amount of natural gas produced, which is almost 4,000 billion m^3/year (bcm/a) (Enerdata, 2019). Therefore, this industry will need a lot more time to establish itself in order to equal the output of natural gas.

However, there is enough evidence to show that synthetic gas could one day substitute the supply of natural gas. At the very least, it could significantly slow down the consumption of fossil fuels by applying a hybrid solution (i.e. Synthetic gas produced from biomass and coal). This would give the world more time to improve upon its technology and find a more sustainable solution. “After all, even if all cars were to drive electrically one day, aircraft, ships, and even trucks will still run mainly on fossil fuel. Carbon-neutral combustion engines that run on synthetic fuels are thus a very promising path to explore, also for passenger cars” (Denner, 2019).

Since synthetic gas is still in its early stages of development and seems to be a feasible solution in the future, this report considers the current supply of natural gas in Switzerland as an approximate value of capacity. Therefore, **31,189 GWh/year** was applied to the ENERGYScope calculator (SFOE, 2018).

5.1.7 Heating

District heating will cover approximately 70% because most of the population’s energy consumption comes from the most densely populated areas (ENERGYScope Calculator, 2012). This heating will be provided by a mixture of co-generation, heat pumps and boilers. Distributed heating will cover the other 30% with a mix of solar thermal power, along with boilers, electric heat pumps and thermal heat pumps. The heating fuels will consist of a combination of synthetic gas and wood biomass. Since coal and heating oil will not be considered as a resource in this report.

There was one study conducted in 2015 on a pre-existing polygeneration power plant in Portugal. The study examined the possibility of upgrading and retrofitting the DHC system with a refuse-derived fuel (RDF) from municipal solid waste, air-steam gasifiers and gas upgrading equipment. The study found that not only could the proposed system produce heat and cold, but it could also be able to produce Synthetic Gas. The system could be able to simultaneously produce 60.3 GWh/year of heat, 65.1 GWh/year of cold, 33.2 GWh/year of electricity and 789.5 tons/year of synthetic natural gas (Natalia Kabalina and et al., 2016). This study proves that applying a system like this in Switzerland would have many advantages in supplying heat, cooling, electricity and synthetic gas. The ability to apply this solution as a "retro-fit" seems to be the biggest advantage since it could be implemented easier and not produce waste from demolishing and constructing a new building. Knowing that it is possible to have a DHC installation work as a multi-functioning system is encouraging.

5.1.8 Sensitivity Analysis of Demand Efficiency

The figure below shows the key parameters contributing to the results of the scenarios. For a more detailed description, refer to **Section 3.6.1 Input Parameters.**

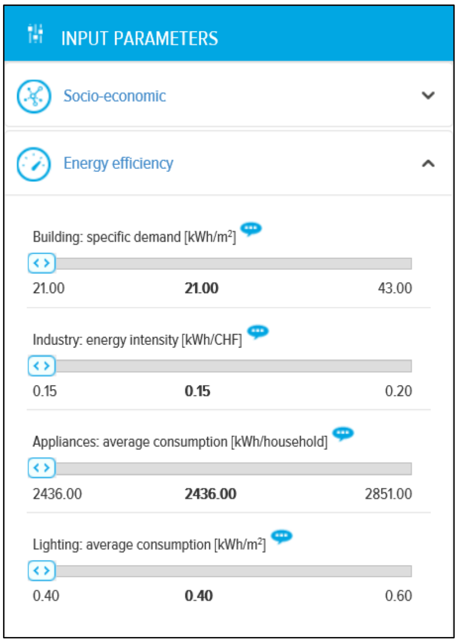

Figure 49: Energy Efficiency Demand Parameters (ENERGYScope Calculator, 2012)

A sensitivity analysis was created to show the minimum, average and maximum effect each efficiency parameter has on the total final energy consumption (TFEC). To create the diagram, each parameter was adjusted individually and recorded according to the change in GWh/year of the TFEC. The "Combined" portion of the diagram consists of adjusting the four slider parameters simultaneously, according to their minimum, average and maximum values.

The most sensitive parameter is the "Appliances" since it seems to have the biggest effect. According to the ENERGYScope Calculator, the appliances annual average electricity consumption includes the electricity used by:

- Appliances that can be found in the kitchen (stoves, oven, fridge/freezer, dishwasher and other cooking auxiliaries).
- Washing machine and dryer.
- IT and audio-visual (TV, computer, gadgets, etc.)
- Air conditioning and ventilation systems.
- Other (hair dryer, iron, vacuum cleaner, etc.)

This list consists of items that are used constantly throughout the day. Therefore, adjusting the slider efficiency from minimum to maximum can make a big difference in energy consumption. Furthermore, modern household appliances often require less energy to provide the same useful service; therefore, efficiency of an appliance makes a big impact on energy demand if it is an older model (ENERGYScope Calculator, 2012).

The least sensitive parameter is the "lighting" since it barely effected the TFEC when adjusted. This could be due to the increase in quality of lightbulbs. According to the Prognos 2012 report, "Compact fluorescent lamps (CFLs) and light emitting diodes (LEDs) are the two most efficient technologies. Compared with a traditional tungsten-filament (incandescent) bulb, CFLs offer a 75% electricity savings and LEDs 80%" (PROGNOS, 2012).

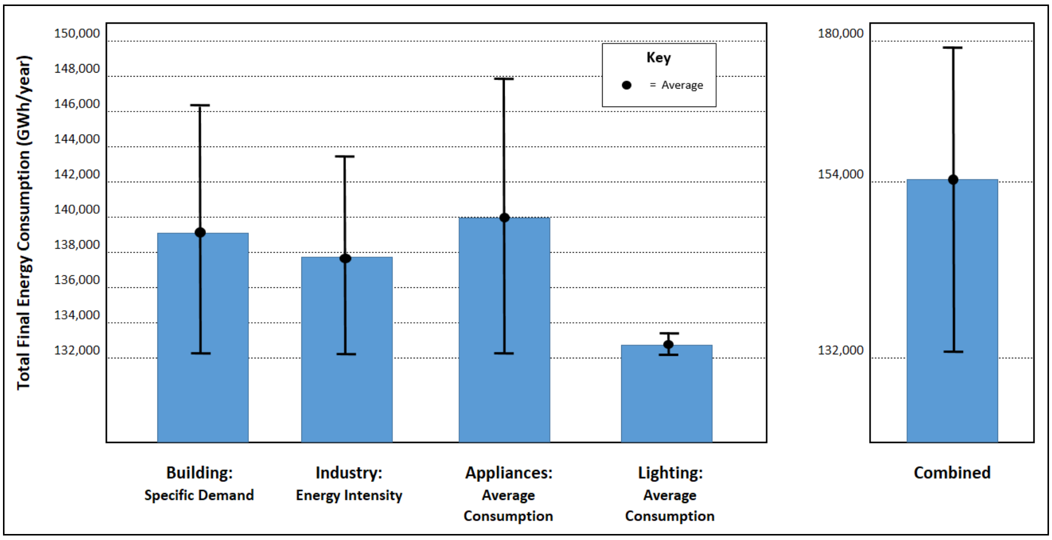

Figure 50: Sensitivity Analysis Diagram

5.2 The Scenarios

This section describes the results for the five proposed scenarios regarding total final energy consumption, electricity, renewables, CO2 emissions, waste and yearly cost of maintenance. Scenarios 2 and 5 are chosen as the only feasible solutions for Switzerland to achieve 100% self-sufficiency with 100% renewable sources. These two scenarios are able to produce enough energy to meet the yearly, seasonal and monthly demand.

5.2.1 Scenario 1: Application of 100% Global Renewable Case Study to Switzerland

The first scenario's results are taken from a case study conducted by LUT University and the Energy Watch Group. It is titled, Global Energy System Based On 100% Renewable Energy, which provides a solution for how the entire world could generate all its energy just from renewable sources. The study believes that it is possible that the world could achieve this goal in the future and what's more astonishing, is they believe it could even be achieved today with the current technology (LUT and EWG, 2019). However, the results of the study are based off each region of the world working together to ensure that supply meets the demand.

The Figure below compares the percentages of energy in 2015 with the case study's proposed percentages of 2050. As you can see, the results comprise mostly of solar PV and wind energy. The primary energy supply will consist of a "mix of sources, with solar PV generating 69%, followed by wind energy (18%), biomass and waste (6%), hydro (3%) and geothermal energy (2%) by 2050. Wind energy and solar PV make up 96% of total electricity and approximately 88% of the total energy supply, which will have a synergetic balancing effect" (LUT and EWG, 2019).

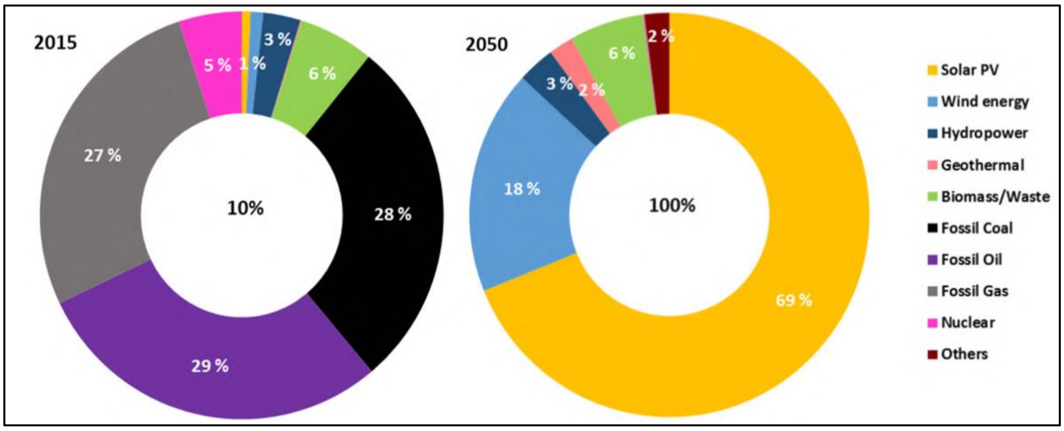

Figure 51: Percentage of Energy Solution (LUT and EWG, 2019)

This case study solution seems like a great idea but when it is applied to Switzerland, the numbers do not translate (See **Table 15** below). The table shows the comparison between the maximum output of Swiss energy production and the Global Case Study values. The values for the Global Case Study solution were achieved by applying the percentages to the lowest energy demand estimated for Switzerland by 2050 (139,000 GWh/year made from multiple literature sources). The table shows in "red" the deficit for solar PV and wind along with the surplus of hydropower, geothermal (excluding deep geothermal) and biomass in "green". The result is a deficit of 16,720 GWh/year. The maximum Swiss output of solar PV would not be able to make up 69% of the energy supply, nor would the 18% of wind power. The country currently does not have any renewable source capable of achieving that high of output percentage. They would require a solution that is made up of multiple energy sources working together, rather than just one or two main sources. Furthermore, applying these percentages to Switzerland would require energy from imports to cover the difference. Therefore, in conclusion, Scenario 1 would not be a feasible solution for Switzerland to achieve 100% self-sufficiency with 100% renewable energy.

Scenario 1							
Global Scenario From Case Study Applied to Swiss lowest consumption estimation for 2050. Estimated Lowest Consumption from EnergyScope tool							
Global Solution Case Study (GWh/year)		%	Switz MAX Scenario (GWh/year)		%	Global Solution Applied to Switz MAX (Difference)	Could this be a possibility?
Solar PV	95,910	69%	Solar PV	25,000	20.44%	-70,910	NO
Wind	25,020	18%	Wind	10,000	8.18%	-15,020	NO
Hydro	4,170	3%	Hydro	37,500	30.67%	33,330	YES
Geothermal	2,780	2%	Geothermal	20,000	16.36%	17,220	YES
Biomass	8,340	6%	Biomass	27,000	22.08%	18,660	YES
Other	2,780	2%	Other	2,780	2.27%	0	Maybe
Total	**139,000**	**100%**	**Total**	**122,280**	**100%**	**-16,720**	**NO**

Table 15: Scenario 1 Results
(LUT and EWG, 2019) (ENERGYScope Calculator, 2012) (Oliver Thees, et. al, 2017)

The point of presenting this case study as a scenario is to show that every country has its own strengths and weaknesses. Achieving 100%, renewable energy is difficult to accomplish independently from the rest of the world. However, Scenario 2 proves that even though it is difficult, it can be done.

5.2.2 Scenario 2: Maximum Capacity of Renewable Sources Combined with *Maximum* Energy Efficiency (Max Supply / Min Demand)

As previously mentioned, Scenario 2 would be a possible solution for Switzerland by 2050. This can be accomplished by applying the maximum amount of domestically produced renewable energy, to the minimum amount of energy demand (139,000 GWh/year or 500,000 Tj/year, estimated by the Prognos 2012 report).

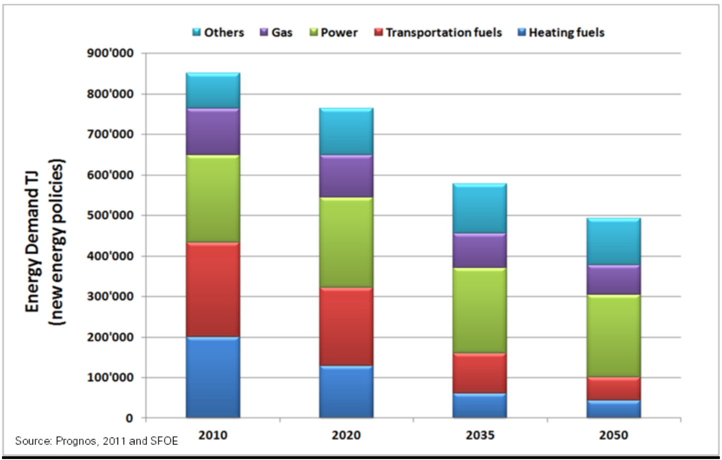

Figure 52: Estimated Energy Demand for Switzerland in 2050 (Katharina Link, et al., 2015) (PROGNOS, 2012)

The two tables below present the maximum renewable energy that can be produced in Switzerland. When analysing **Table 16: Scenario 2a**, it can be seen that the total production amount has a surplus of 12,500 GWh/year. This scenario is able to meet energy demand monthly and annually but it does not have a lot of room for flexibility or adjustment to the system. It would have to be ran at full capacity all year. However, the 25,000 GWh/year from solar PV in Scenario 2a is based off an older estimation from 2012. As previously mentioned in Section 5.1, this is the highest quantity of solar PV that can be applied to the ENERGYScope Calculator. Since the SFOE has made a recent estimation of 67,000 GWh/year, the results of Scenario 2 will be referred to as Scenario 2a and Scenario 2b in order to incorporate the graphs.

Observing **Table 17: Scenario 2b** shows that when the higher quantity of solar PV is applied, the energy supply far exceeds the energy demand. The 54,500 GWh/year in surplus reduces the pressure of Switzerland having to achieve maximum capacity with all its production sources. It also allows the overall energy demand to not have to achieve its theoretical minimum for this scenario to be successful. In other words, this scenario allows for flexibility, freedom and adaptability of the entire energy system.

Scenario 2		
Minimum Total Final Energy Consumption combined with Maximum Total Renewable Energy Production		
Switz MAX Scenario (GWh)		%
Solar PV	25,000	16.50%
Wind	10,000	6.60%
Hydro	37,500	24.75%
Deep Geothermal	0	0.00%
Biomass	27,000	17.82%
Geothermal Heat Pumps	20,000	13.20%
Sub Total	**119,500**	**78.88%**
Synthetic Gas	32,000	21.12%
Total	**151,500**	**100.00%**
Minimum Switz Consumption	139,000	
Surplus	**12,500**	

Table 16 Left: Scenario 2a

Scenario 2		
Minimum Total Final Energy Consumption combined with Maximum Total Renewable Energy Production		
Switz MAX Scenario (GWh)		%
Solar PV	67,000	34.63%
Wind	10,000	5.17%
Hydro	37,500	19.38%
Deep Geothermal	0	0.00%
Biomass	27,000	13.95%
Geothermal Heat Pumps	20,000	10.34%
Sub Total	**161,500**	**83.46%**
Synthetic Gas	32,000	16.54%
Total	**193,500**	**100.00%**
Minimum Switz Consumption	139,000	
Surplus	**54,500**	

Table 17 Right: Scenario 2b

Scenario 2 not only allows the *yearly* total final energy demand to be met, it can also provide energy for every *month* during the year. The coldest months have always required the most energy, forcing Switzerland to import energy from neighbouring countries (SFOE, 2018). The warmer months have had the opposite effect, allowing Switzerland to export surplus energy (SFOE, 2018). However, Scenario 2a is capable of producing a surplus in electricity seven months out of the year (See **Figure 53** below). Note: this graph only reflects the 25,000 GWh/year from solar PV and not the 67,000 GWh/year because of the limitations of the ENERGYScope Calculator. Therefore, because of the large surplus from Scenario 2b, it can be assumed that a surplus in electricity would be possible for every month during the year.

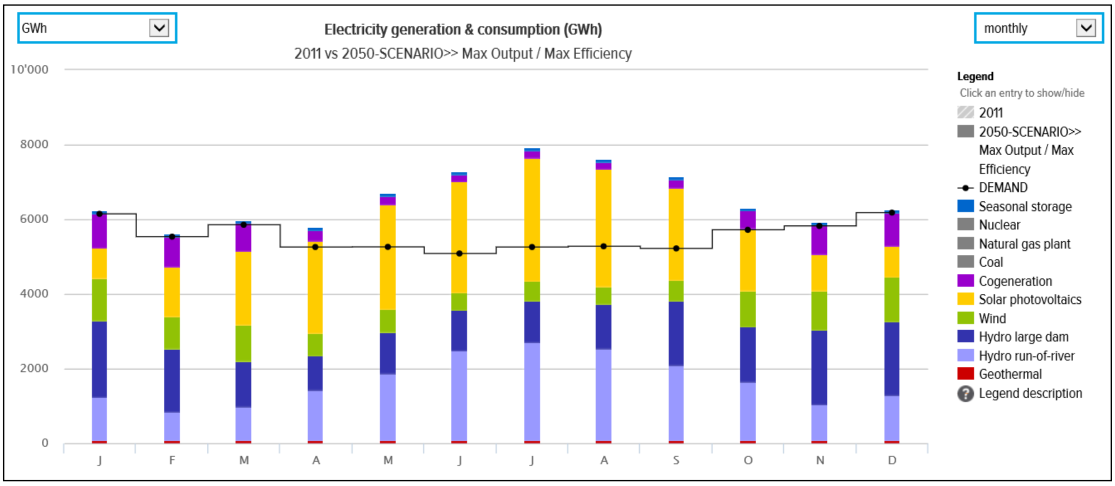

Figure 53: Scenario 2a Monthly Electricity Generation (ENERGYScope Calculator, 2012)

One possible solution to save the high surplus of electricity during the year would be to create a storage system using a Power-to-Gas plant (P2G) (Natalia Kabalina and et al., 2016). The surplus of electricity, mostly from solar, can be used to create hydrogen, which can be used later during the year or to supply hydrogen to hydrogen-fuelled vehicles. The 100% Global Renewable case study estimates that P2G would contribute to around 40% of the heat storage output in 2050 (LUT and

EWG, 2019). Therefore, instead of importing excess electricity, it can be used domestically in other areas.

The distribution of renewable energies can be seen in the figure below. Energy from solar and hydro work together to counterbalance the energy from heat pumps and synthetic gas. When solar and hydro are higher during the warmer months, synthetic gas and heat pumps are lower. When synthetic gas and heat pumps are higher during the colder months, solar and hydro are lower. Biomass and wind energies are, for the most part, consistent throughout the year.

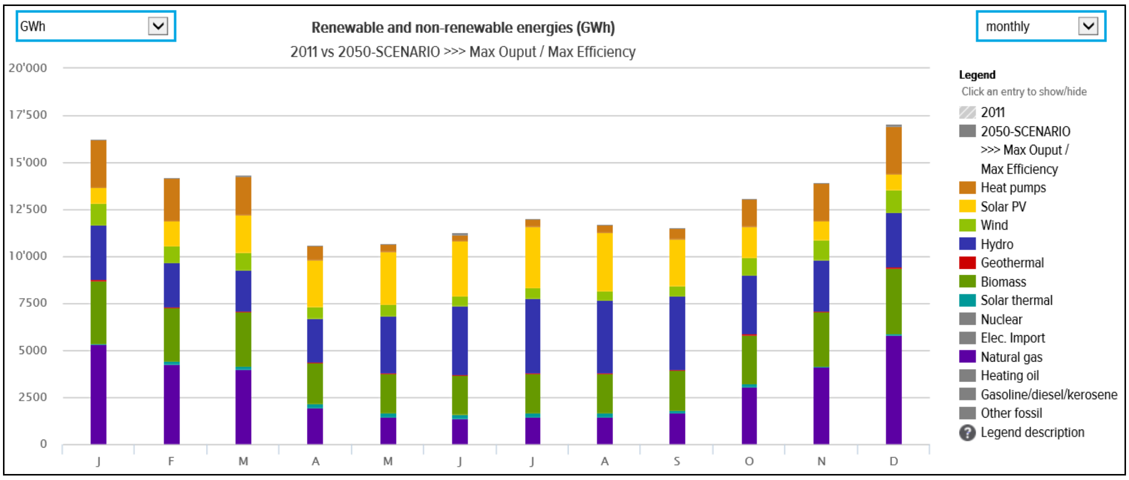

Figure 54: Monthly Distribution of Renewable Energies

The CO2 emissions and quantity of waste is reduced significantly when compared to the values of 2011. When Switzerland signed the Paris Agreement in 2016, the government said its long-term goal is to reduce carbon emissions by 70-85% by 2050 (SwissInfo, 2019). The amount of reduction in this scenario is about 78% ((9,837/44,516) - 1), which aligns right in the middle of Switzerland's CO2 emission goals. The amount of waste reduction is also significant with a total decrease of about 95% ((439/9,261) - 1).

Annual costs to run the system rose only about CHF 3 million compared to the costs in 2011. The CHF 24,717 million fits right in the middle of the costs of Scenario's 3 and 4 which are CHF 24,167 and CHF 24,951 million, respectively. For a detailed description of how the costs were calculated, refer to **Section 3.6.1** and **3.6.2**.

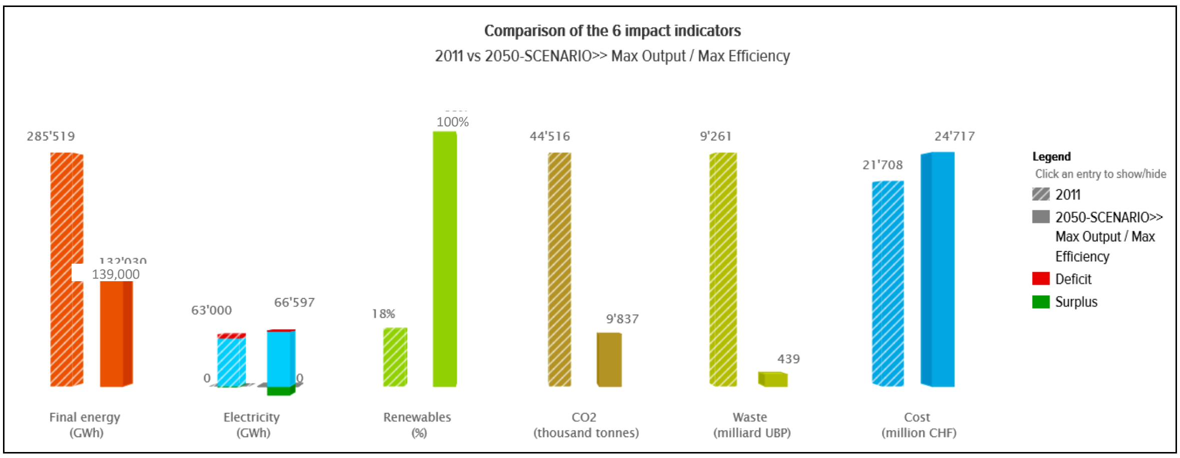

Figure 55: Scenario 2a All Impact Indicators Comparison to 2011 (ENERGYScope Calculator, 2012)

The next section of the evaluation of Scenario 2 includes a SWOT and PESTEL analysis. The results for each can be seen in the tables below. The SWOT Analysis considers only *internal* factors regarding Scenario 2 while the PESTEL analysis consists of only *external* factors. The external factors of the PESTEL analysis also only contains the "negative" aspects that could impede or prevent the implementation of the system.

	SWOT Analysis (Internal Factors)	
Scenario 2	Strengths	Weaknesses
	• Meets monthly and annual energy demands • Meets Swiss CO2 goals • Cleaner and healthier environment • Less reliance on other countries for energy • Better efficient systems (smart-grids, etc.) • Infinite amount of energy/electricity in comparison to fossil fuel • Self-satisfaction from improving the world • Sustainable system • Uses human and animal waste as fuel • Less overall wasted energy	• High amount of costs for installations • Requires a lot more land and surface area • Requires many new policies to help with financial costs • Most likely will result in higher taxes • Waste from non-retro fitted vehicles and structures • Requires non-fossil fuelled vehicles • A complete restructure of vehicle re-fuelling stations • CO2 emissions are very low but not completely zero • Requires a complete restructuring of the entire electricity grid
	Opportunities	Threats
	• Self-awareness of people's individual effects on the planet (waste, overconsumption, etc.) • Higher average lifespan • New job training and university classes incorporated • Provide an infinite, healthy and sustainable energy system • Higher total jobs available • Inspire new technologies that can contribute to the new system • Improve quality of life	• Culture change and acceptance of new ways of doing things could hinder progression (different "foreign" technologies, no muscle cars, etc.) • Policy decisions take too long to be made or accepted • Less technology advancement than originally assumed • Land owners oppose wind power, solar PV, power plant installations • Costs are too high to pay for renewable source max capacities • Takes longer than 30 years to implement entire system • Aggressive threats from fossil-fuel owned companies (terrorists, mob, oil tycoons) • Unforeseen circumstances • Too difficult to install the system

Table 18: SWOT Analysis for Scenario 2

PESTEL Analysis (External Factors)		
Scenario 2	Political	• Government is slow to make changes and decisions • The population doesn't agree on renewable transition (voting) • Negative propaganda from different political groups • Weak laws and regulations that don't promote renewable transition • Inadequate relay of important information • Does not offer enough help to wood(biomass) companies to make it profitable for them to stay in business • Not strong enough "will" to make the population see that this is the only way to achieve 100% renewable energy and 100% self-sufficiency
	Economical	• People cannot afford to pay for the new system, costs are too high • The government's subsidies and programs are not enough help • Renewable energy businesses raise prices because of high demand • Electric, synthetic gas and hydrogen Vehicles are too expensive • Too high interest rates on loans as a result of a high increase in bank loans to pay for system
	Sociological	• Neighbouring countries hold resentment towards Switzerland's "energy isolation" resulting in closed borders, higher fees, and higher taxes on non-energy related exports • Resistance from Swiss people to accept new ways of doing things and change in culture • The population does not consider the energy transition "worth it" when compared to cost and challenge of implementing
	Technological	• Development of synthetic gas does not prove to be a capable and sufficient substitution for natural gas • Not a significant improvement to renewable source efficiencies or efficiencies regarding the demand of appliances, industry, mobility and lighting • Storage and batteries do not improve enough to be reliable for long periods of time
	Environmental	• Available Land and surface area of Switzerland is reduced • Risk of requiring too much deforestation to supply wood biomass • Animal safety risks (windmills, deforestation, etc.) • Too much waste from new structures and old vehicles that needs to be disposed of (increase in burning waste results in increase in CO2 emissions) • Effects on animal population and habitat resulting from increase need for hydropower • Synthetic gas leakage
	Legal	• Laws and restrictions holding back development, i.e. outdated laws that do not reflect the current change • Overprotection or too strict of laws on issues where there is not enough information, or lack of research to provide definitive results

Table 19: PESTEL Analysis for Scenario 2

One main barrier for any system is always the cost. Who is going to pay for the renovations and instalments of the new system? Solar power is becoming less expensive than it used to be but it still requires a large up-front deposit. According to one source, "energy efficiency renovations generally call for substantial additional up-front investments, as compared to repairing or overhauling options. The extra upfront costs of window replacement are also considerable if the state of the windows does not call for replacement or if repair and painting is possible (350 to 500 CHF/m2, depending on the reference case)" (Jakob, 2007).

Another key aspect of implementing a new system is the policies involved. It will require a lot of assistance from the Swiss Federal government to support its citizens and businesses financially. They will also need to convince the population that the benefits of the new system is worth the time and money for future generations. That it is in Switzerland's best interest as a country, society and culture to provide security for the next generation. Ronald Reagan once said, "Each generation goes further than the generation preceding it because it stands on the shoulders of that generation. You will have opportunities beyond anything we've ever known" (Brainy Quote, 2020).

5.2.3 Scenario 3 (Max Supply / Max Demand) and Scenario 4 (Average Supply / Average Demand Efficiency)

As previously mentioned, Scenario 3 and 4 do not qualify as reasonable solutions. One reason for this is they both are unable to meet the energy demand throughout the year. They are only able to generate enough electricity during the summer season. The demand is too high for Scenario 3 and the values for Scenario 4 are much less at meeting demand. The values applied for the maximum amount of solar PV are 25,000 GWh/year in both scenarios. However, even when applying the higher estimated amount of 67,000 GWh/year made by the SFOE, it would not leave much freedom for adjustments and flexibility. Therefore, Scenario 3 and 4 would be harder to achieve than Scenario 2b.

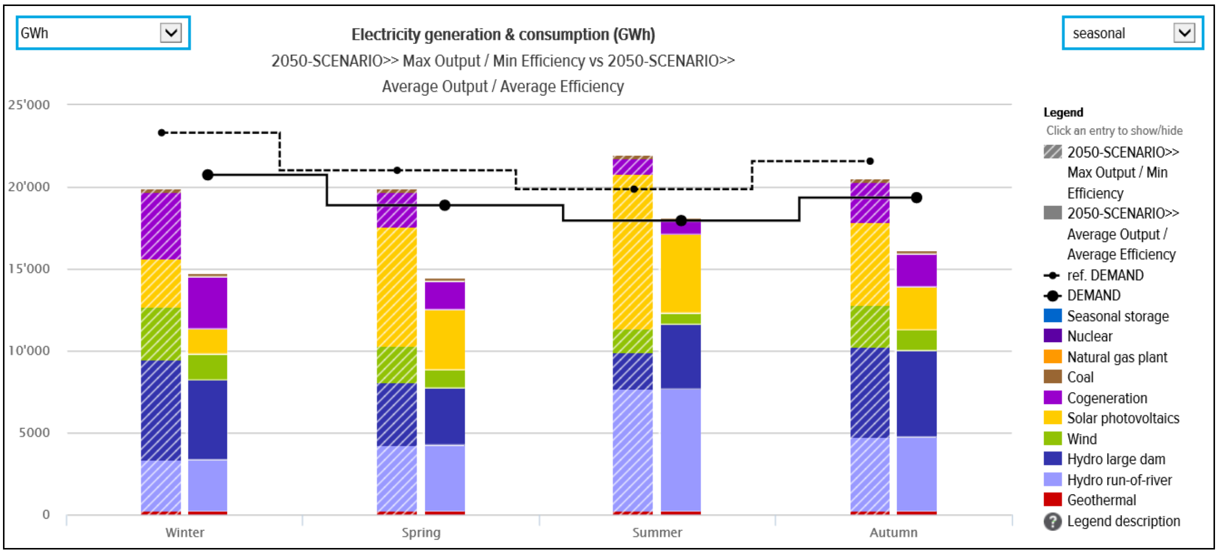

Figure 56: Electricity Comparison between Scenario 3 and 4

There are some positive aspects of these two scenarios. The amount of CO_2 emissions and wasted energy are much less when compared to the 2011 values. The yearly maintenance and investment costs are higher than 2011, but that is the case with all of the proposed scenarios (Scenarios 2, 3 and 4).

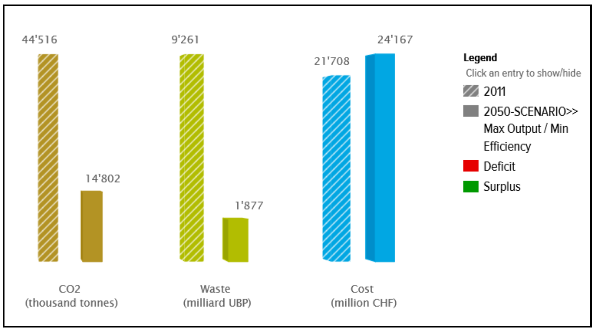

Figure 57: Scenario 3 vs. 2011

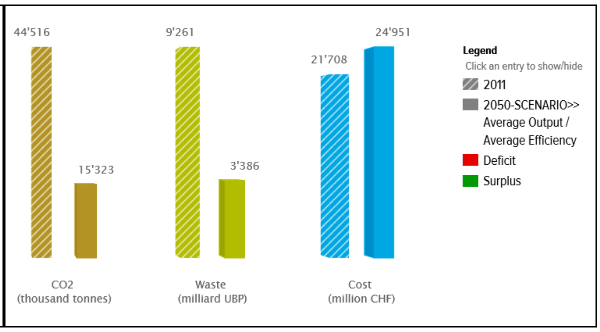

Figure 58: Scenario 4 vs. 2011

The amount of final energy consumption and electricity are quite similar with these two scenarios, but are much higher when compared to the "best case" Scenario 2b. This is mostly due to the less efficient productivity and higher demand regarding buildings, appliances, lighting and industry intensity.

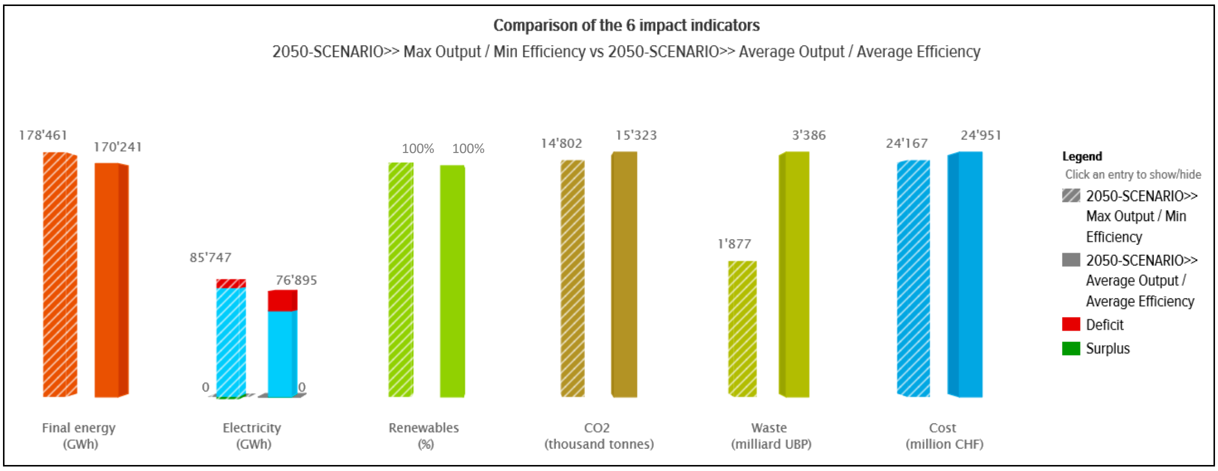

Figure 59: Comparison between All Impact Indicators for Scenario 3 and 4

In conclusion, Scenario 3 and 4 show a lot of potential as solutions to self-sufficiency. When viewing the "big picture" of the timeline of Switzerland's overall progress from 2020 until 2050, these scenarios would most likely fall somewhere in between. It could be assumed that with the right policies and structure of financial support, the values from the "Average Supply / Average Demand Efficiency" scenario would be an eventual milestone along the way to the final goal of this report (100% renewable energy and 100% self-sufficiency).

5.2.4 Scenario 5: Technology Advancement Combined with Scenario 2

Scenario 5 consists of taking the results from Scenario 2 and building upon them in terms of improvement in all areas of energy: supply and demand efficiencies, policy changes, cultural habits and acceptance of different solutions, etc.

The fifth and final scenario of this report does not provide graphs and figures from the ENERGYScope calculator. It also does not have any exact "numbers" to be used as a comparison. It is rather a "thought-provoking" scenario in which it is possible to imagine that within the next 30 years there will be some amount of advancement in technology. Current discoveries are moving at an exponential rate and therefore, it is possible to assume that there will be significant contributions to Scenario 2. After reviewing the previous five scenarios, it is possible to envision the capability of self-sufficiency with renewable sources being achieved. Scenario 2 showed that it "can be done" and is in the realm of possibility.

Improving upon renewable source efficiencies will significantly improve the overall harvesting of energy, especially the solar PV sector. The higher the efficiency of solar panels, the more energy that can be produced. Furthermore, the appearance of solar panels will also improve, which is one of the biggest complaints about solar PV systems. Many people say that they are visually unappealing; however, there has already been great improvements to their overall aesthetics.

For example, Elon Musk, CEO of Tesla, unveiled his product for the first time to investors in 2016. The technology consists of crystalline solar cells that are embedded within a roofing tile and can only be seen from a certain angle. The solar cells are not visible from a "street view" and look like normal roofing shingles (See Images Below).

Figure 60: Tesla Solar "Terra Cotta" Tile (Sivasamy, 2017)

There are also other options to choose from that look exactly like normal roofing tiles (See image below). The biggest drawback to these solar panels is the cost, ranging from $20,000 to $50,000 (Tarbi, 2018). However, if these costs were to be reduced over the next 30 years, these could become a feasible option.

Figure 61: Tesla Solar Roof Tile Product Selection (Sivasamy, 2017)

Other technologies are also being developed, such as solar powered windows. The example below is a solar powered window using Dye-sensitized solar cells. This technology was first discovered in 1991 by Ecole Polytechnique Federale De Lausanne (EPFL) in Switzerland by professor Michael Graetzel (RomandeEnergie, 2013). It reproduces principles of photosynthesis in plants and was later installed on the school's convention center in 2014 as the first ever-coloured PV window installation (RomandeEnergie, 2013). It is semi-transparent and can also be used to shade the building from direct sunlight.

Figure 62: EPFL School Convention Center (RomandeEnergie, 2013)

Batteries and transportation is another area where a vast improvement would make an enormous difference to the current energy industry. One research group named Det Norske Veritas, states that if within the next 10 years the energy density of batteries is doubled, a "vehicle such as the Tesla Model S won't have 300 miles of range, but 600. Conversely, if the battery pack volume is cut in half, a Tesla Model S cost may be reduced as much as 50% because less battery is needed for the same performance, and the battery is the bulk of the vehicle cost" (DNV GL, 2019). Regarding smaller vehicles like the Tesla Model 3 or Hyundai Kona EV, the range of travelling distance could be "doubled or prices could be reduced 25-50%, indicating that a practical EV with long range will be had for a price in the $20,000's" (DNV GL, 2019). Improvements like these would make a huge difference to the energy sector since transportation/mobility is one of the biggest obstacles to overcome to achieve 100% renewable energy.

Some researchers are already assuming that there will be a big improvement in battery technology over the next 30 years. According to LUT University, they estimate that in 2050 "energy storage will meet nearly 23% of electricity demand and approximately 26% of heat demand. Batteries will emerge as the most relevant electricity storage technology and thermal energy storage emerges as the most relevant heat storage technology" (LUT and EWG, 2019).

In conclusion, self-sufficiency of a single country will be difficult to achieve. With the right policies and commitment, there are many countries who could theoretically achieve this. However, is the alienation of one country from the rest of its neighbours something that should be strived for? We only have one planet that encloses us all. Each country has their strengths and weaknesses. Therefore, the world must work together and use the strengths of one nation to support the weaknesses of another. However, an advancement in technology over the next 30 years to key areas of the energy industry, combined with the results from Scenario 2, prove to be a feasible solution to a 100% renewable energy source and 100% self-sufficient Switzerland.

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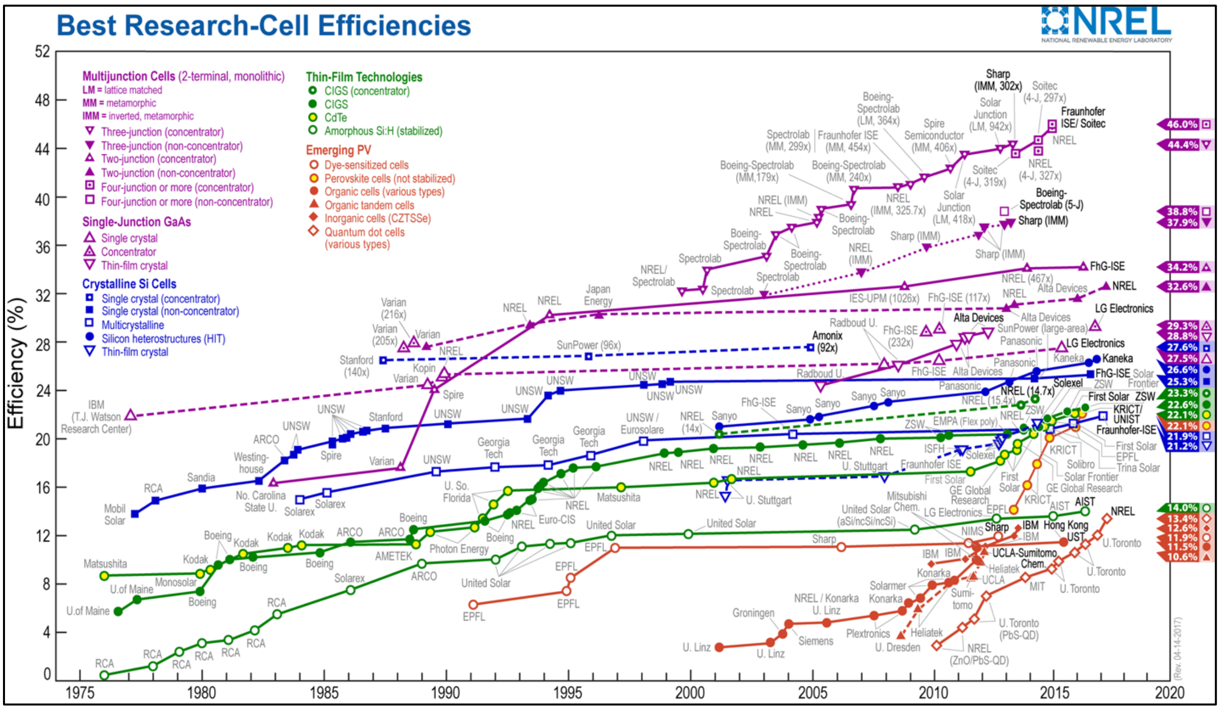
Appendix



Efficiencies of Solar Panel Categories (NREL N. R., 2017)

Tab. 24 Elektrizitätserzeugung
Production d'électricité

BFE, Schweizerische Gesamtenergiestatistik 2018 (Tab. 24)
OFEN, Statistique globale suisse de l'énergie 2018 (tabl. 24)

Jahr / Année	Wasserkraftwerke / Centrales hydrauliques: Laufwerke / Centrales au fil de l'eau	Speicherwerke / Centrales à accumulation	Total		Kernkraftwerke / Centrales nucléaires		Konventionell-thermische Kraft- und Fernheizkraftwerke[1] / Centrales thermiques class. et centrales chaleur-force[1]: Total		Davon erneuerbar[2] / Dont renouvelable[2]		Diverse erneuerbare Energien[3] / Energies renouvelables diverses[3]: Feuerungen mit Holz und Holzanteilen / Chauffages au bois et en partie au bois	Biogasanlagen / Installations au biogaz	Photovoltaikanlagen / Installations photovoltaïques	Windenergieanlagen / Eoliennes	Total		Landeserzeugung (brutto) 100 % / Production nationale (brute) 100 %	Verbrauch der Speicherpumpen / Pompage d'accumulation	Nettoerzeug. (Speicherpumpen abgezogen) / Production nette (pompage déduit)
	GWh	GWh	GWh	%	GWh	%	GWh	%	GWh	%	GWh	GWh	GWh	GWh	GWh	%	GWh	GWh	GWh
1970	13 758	17 515	31 273	89,6	1 850	5,3	1 763	5,1	–	–	–	–	–	–	–	–	34 886	965	33 921
1975	14 039	19 935	33 974	79,0	7 391	17,2	1 629	3,8	–	–	–	–	–	–	–	–	42 994	1 198	41 796
1980	14 967	18 575	33 542	69,6	13 663	28,4	957	2,0	–	–	–	–	–	–	–	–	48 162	1 531	46 631
1981	16 173	19 924	36 097	70,0	14 462	28,1	956	1,9	–	–	–	–	–	–	–	–	51 515	1 395	50 120
1982	15 617	21 418	37 035	70,8	14 276	27,3	974	1,9	–	–	–	–	–	–	–	–	52 285	1 532	50 753
1983	15 234	20 768	36 002	69,5	14 821	28,6	996	1,9	–	–	–	–	–	–	–	–	51 819	1 346	50 473
1984	14 051	16 821	30 872	62,8	17 396	35,4	884	1,8	–	–	–	–	–	–	–	–	49 152	1 444	47 708
1985	13 765	18 912	32 677	59,6	21 281	38,8	869	1,6	–	–	–	–	–	–	–	–	54 827	1 364	53 463
1986	14 013	19 576	33 589	60,1	21 303	38,1	988	1,8	–	–	–	–	–	–	–	–	55 880	1 461	54 419
1987	14 863	20 549	35 412	60,9	21 701	37,3	1 048	1,8	–	–	–	–	–	–	–	–	58 161	1 564	56 597
1988	15 437	21 002	36 439	61,8	21 502	36,5	1 023	1,7	–	–	–	–	–	–	–	–	58 964	1 445	57 519
1989	13 613	16 872	30 485	57,4	21 543	40,6	1 082	2,0	–	–	–	–	–	–	–	–	53 110	1 454	51 656
1990	13 561	17 114	30 675	56,8	22 298	41,2	1 013	1,9	352	0,7	6	80	1	0	88	0,2	54 074	1 695	52 379
1991	13 898	19 184	33 082	59,0	21 654	38,6	1 247	2,2	343	0,6	6	87	2	0	95	0,2	56 078	1 946	54 132
1992	15 219	18 506	33 725	58,8	22 121	38,6	1 393	2,4	379	0,7	11	95	3	0	109	0,2	57 348	1 438	55 910
1993	15 451	20 802	36 253	61,2	22 029	37,1	913	1,5	377	0,6	8	106	4	0	118	0,2	59 313	1 186	58 127
1994	16 590	22 966	39 556	62,1	22 984	36,1	988	1,6	423	0,7	10	117	5	0	133	0,2	63 661	1 271	62 390
1995	16 148	19 449	35 597	59,0	23 486	38,9	1 137	1,9	443	0,7	9	122	6	0	138	0,2	60 358	1 520	58 838
1996	13 669	16 029	29 698	53,9	23 719	43,0	1 556	2,8	474	0,9	14	126	7	1	147	0,3	55 120	1 754	53 366
1997	14 695	20 099	34 794	57,4	23 971	39,6	1 686	2,8	519	0,9	10	129	7	2	149	0,2	60 600	1 519	59 081
1998	14 966	19 329	34 295	56,3	24 368	40,0	2 124	3,5	539	0,9	13	137	8	3	161	0,3	60 948	1 620	59 328
1999	16 640	23 976	40 616	60,9	23 523	35,3	2 386	3,6	594	0,9	13	142	10	3	168	0,3	66 693	1 408	65 285
2000	17 566	20 285	37 851	57,9	24 949	38,2	2 372	3,6	670	1,0	14	149	11	3	176	0,3	65 348	1 974	63 374
2001	17 751	24 510	42 261	60,3	25 293	36,0	2 433	3,5	705	1,0	14	157	13	4	187	0,3	70 174	1 947	68 227
2002	17 625	18 888	36 513	56,2	25 692	39,5	2 612	4,0	735	1,1	22	152	15	5	194	0,3	65 011	2 418	62 593
2003	15 398	21 047	36 445	55,9	25 931	39,7	2 689	4,1	752	1,2	27	151	18	5	201	0,3	65 266	2 893	62 373
2004	16 039	19 078	35 117	55,3	25 432	40,0	2 776	4,4	797	1,3	29	144	18	6	198	0,3	63 523	2 433	61 090
2005	14 998	17 761	32 759	56,6	22 020	38,0	2 932	5,1	838	1,4	33	145	21	8	207	0,4	57 918	2 631	55 287
2006	15 819	16 738	32 557	52,4	26 244	42,2	3 103	5,0	937	1,5	44	154	24	15	237	0,4	62 141	2 720	59 421
2007	16 547	19 826	36 373	55,2	26 344	40,0	2 894	4,4	919	1,4	92	168	29	16	305	0,5	65 916	2 104	63 812
2008	16 686	20 873	37 559	56,1	26 132	39,0	2 913	4,3	921	1,4	131	177	37	19	363	0,5	66 967	2 685	64 282
2009	16 110	21 026	37 136	55,8	26 119	39,3	2 817	4,2	884	1,3	154	191	54	23	422	0,6	66 494	2 523	63 971
2010	16 030	21 420	37 450	56,5	25 205	38,1	3 123	4,7	928	1,4	135	209	94	37	474	0,7	66 252	2 494	63 758
2011	14 733	19 062	33 795	53,7	25 560	40,7	2 866	4,6	963	1,5	193	229	168	70	660	1,0	62 881	2 466	60 415
2012	17 832	22 074	39 906	58,7	24 345	35,8	2 869	4,2	1 015	1,5	252	260	299	88	899	1,3	68 019	2 411	65 608
2013	17 759	21 813	39 572	57,9	24 871	36,4	2'722	4,0	1 050	1,5	278	279	500	90	1 147	1,7	68 312	2 132	66 180
2014	17 243	22 065	39 308	56,5	26 370	37,9	2'449	3,5	1 108	1,6	273	290	842	101	1 506	2,2	69 633	2 355	67 278
2015	16 595	22 891	39 486	59,9	22 095	33,5	2'661	4,0	1 115	1,7	184	303	1 119	110	1 715	2,6	65 957	2 296	63 661
2016	16 574	19 752	36 326	59,0	20 235	32,8	3'070	5,0	1 182	1,9	223	320	1 333	109	1 985	3,2	61 616	2 922	58 694
2017	15 946	20 720	36 666	59,6	19 499	31,7	2 851	4,6	1 182	1,9	322	334	1 683	133	2 471	4,0	61 487	4 160	57 327
2018	16 908	20 520	37 428	55,4	24 414	36,1	3 008	4,5	1 169	1,7	290	352	1 944	122	2 708	4,0	67 558	3 987	63 571

Electricity Production of Switzerland 2018

Tab. 1 Gesamter Endverbrauch an Energieträgern
Consommation finale totale d'agents énergétiques

Energieträger	Endverbrauch in Originaleinheiten / Consommation finale en unités originales 2017	2018	Endverbrauch in TJ / Consommation finale en TJ 2017	2018	Veränderung in % / Variation en % 2017–2018	Anteil in % / Part en % 2017	2018	Agents énergétiques
Erdölprodukte	9743000 t	**9556000 t**	418020	**409930**	– 1,9	49,2	**49,3**	**Produits pétroliers**
davon:								dont:
Erdölbrennstoffe	2983000 t	**2699000 t**	127930	**115630**	– 9,6	15,1	**13,9**	Combustibles pétroliers
davon:								dont:
Heizöl extra-leicht	2884000 t	**2593000 t**	123720	**111240**	–10,1	14,6	**13,4**	Huile extra-légère
Heizöl mittel und schwer	2000 t	**1000 t**	80	**40**	–50,0	0,0	**0,0**	Huile moyenne et lourde
Petrolkokos	24000 t	**34000 t**	760	**1080**	42,1	0,1	**0,1**	Coke de pétrole
Übrige	73000 t	**71000 t**	3360	**3270**	– 2,7	0,4	**0,4**	Autres
Treibstoffe	6760000 t	**6857000 t**	290100	**294300**	1,4	34,1	**35,4**	Carburants
davon:								dont:
Benzin	2338000 t	**2301000 t**	99600	**98020**	– 1,6	11,7	**11,8**	Essence
Flugtreibstoffe	1758000 t	**1858000 t**	75950	**80270**	5,7	8,9	**9,7**	Carburants d'aviation
Dieselöl	2664000 t	**2698000 t**	114550	**116010**	1,3	13,5	**14,0**	Carburant diesel
Elektrizität[1]	58483 GWh	**57647 GWh**	210540	**207530**	– 1,4	24,8	**25,0**	**Electricité**[1]
Gas[2]	33024 GWh	**31188 GWh**	118880	**112280**	– 5,6	14,0	**13,5**	**Gaz**[2]
Kohle	190000 t	**176000 t**	4610	**4290**	– 6,9	0,5	**0,5**	**Charbon**
Holzenergie	–	**–**	40870	**38310**	– 6,3	4,8	**4,6**	**Energie du bois**
Fernwärme	5503 GWh	**5389 GWh**	19810	**19400**	– 2,1	2,3	**2,3**	**Chaleur à distance**
Industrieabfälle	–	**–**	10670	**10870**	1,9	1,3	**1,3**	**Déchets industriels**
Übrige erneuerbare Energien	–	**–**	26420	**28270**	7,0	3,1	**3,4**	**Autres énergies renouvelables**
davon:								dont:
Biogene Treibstoffe	–	**–**	5520	**7520**	36,2	0,6	**0,9**	Carburants biogènes
Biogas[3]	–	**–**	1740	**1840**	5,7	0,2	**0,2**	Biogaz[3]
Sonne	–	**–**	2510	**2560**	2,0	0,3	**0,3**	Soleil
Umweltwärme	–	**–**	16650	**16350**	– 1,8	2,0	**2,0**	Chaleur ambiante
Total Endverbrauch	–	**–**	849820	**830880**	– 2,2	100,0	**100,0**	**Total consommation finale**

[1] Anteil der erneuerbaren Energien an der Elektrizitätsproduktion siehe Tab. 24
[2] unterer Heizwert (36,3 MJ/Norm m³); in der Gasindustrie wird als Rechnungseinheit der Brennwert (40,3 MJ/Norm m³) verwendet; unterer Heizwert = 0,9 * Brennwert
[3] 2018 wurden zusätzlich 1170 TJ Biogas ins Erdgasnetz eingespeist und unter Gas verbucht (2017: 1080 TJ).

[1] Part des énergies renouvelables dans la production d'électricité, voir tableau 24
[2] Pouvoir calorifique inférieur (36,3 MJ/Norm m³); dans l'industrie du gaz, on utilise comme facteur de conversion en vigueur le pouvoir calorifique supérieur (40,3 MJ/Norm m³); pouvoir calorifique inférieur = 0,9 * pouvoir calorifique supérieur
[3] En 2018, 1170 TJ de biogaz ont en outre été injectés dans le réseau de gaz naturel et comptabilisés sous gaz (2017: 1080 TJ).

BFE, Schweizerische Gesamtenergiestatistik 2018 (Tab. 1)
OFEN, Statistique globale suisse de l'énergie 2018 (tabl. 1)

Energy Consumption of Switzerland 2018

Tab. 17 Endverbrauch nach Verbrauchergruppen in TJ im Jahr 2018
Consommation finale selon les catégories de consommateurs en TJ pour l´année 2018

Energieträger	Haushalte / Ménages 2017	2018	Veränd. in % / Var. en %	Industrie / Industrie 2017	2018	Veränd. in % / Var. en %	Dienstleistungen / Services 2017	2018	Veränd. in % / Var. en %	Verkehr / Transports 2017	2018	Veränd. in % / Var. en %	Statistische Differenz inkl. Landwirtschaft / Différence statistique, y compris l´agriculture 2017	2018	Veränd. in % / Var. en %	Total 2017	2018	Veränd. in % / Var. en %	Agents énergétiques
Erdölprodukte	76210	67980	−10,8	14670	14250	−2,9	34060	30670	−10,0	290100	294300	1,4	2980	2730	–	418020	409930	−1,9	**Produits pétroliers**
davon:																			dont:
Erdölbrennstoffe	76210	67980	−10,8	14670	14250	−2,9	34060	30670	−10,0	–	–	–	2980	2730	–	127930	115630	−9,6	Combustibles pétroliers
davon:																			dont:
Heizöl extra-leicht	76210	67980	−10,8	11590	10950	−5,5	32940	29580	−10,2	–	–	–	2980	2730[1]	–	123720	111240	−10,1	Huile extra-légère
Treibstoffe	–	–	–	–	–	–	–	–	–	290100	294300	1,4	–	–	–	290100	294300	1,4	Carburants
davon:																			dont:
Benzin	–	–	–	–	–	–	–	–	–	99600	98020	−1,6	–	–	–	99600	98020	−1,6	Essence
Diesel	–	–	–	–	–	–	–	–	–	114550	116010	1,3	–	–	–	114550	116010	1,3	Carburant diesel
Flugtreibstoffe	–	–	–	–	–	–	–	–	–	75950	80270	5,7	–	–	–	75950	80270	5,7	Carburants d'aviation
Elektrizität[2]	69220	68710	−0,7	64430	62320	−3,3	62060	61900	−0,3	11340	11120[3]	−1,9	3490	3480[4]	–	210540	207530	−1,4	**Electricité**[2]
Gas	48490	46070	−5,0	40910	39230	−4,1	26460	24580	−7,1	1040	1080[5]	3,8	1980	1320	–	118880	112280	−5,6	**Gaz**
Kohle	100	100	0,0	4510	4190	−7,1	–	–	–	–	–	–	0	0	–	4610	4290	−6,9	**Charbon**
Holzenergie	19580	18300	−6,5	11670	10950	−6,2	8740	8240	−5,7	–	–	–	880	820	–	40870	38310	−6,3	**Energie du bois**
Fernwärme	7740	7530	−2,7	6850	6910	0,9	5220	4960	−5,0	–	–	–	0	0	–	19810	19400	−2,1	**Chaleur à distance**
Industrieabfälle	–	–	–	10670	10870	1,9	–	–	–	–	–	–	0	0	–	10670	10870	1,9	**Déchets industriels**
Übrige erneuerbare Energien[6]	15440	15250	−1,2	1760	1690	−4,0	3430	3390	−1,2	5520	7520	36,2	270	420	–	26420	28270	7,0	**Autres énergies renouvelables**[6]
Total	236780	223940	−5,4	155470	150410	−3,3	139970	133740	−4,5	308000	314020	2,0	9600	8770	–	849820	830880	−2,2	**Total**

[1] Rundungsdifferenzen zu Total Erdölbrennstoffe möglich
[2] Quelle: Elektrizitätsstatistik
[3] Bahnen (inkl. Bergbahnen, Skilifte, Trams, Trolleybus sowie Fahrleitungsverluste)
[4] entspricht dem Endverbrauch der Landwirtschaft
[5] davon Gasverbrauch der Kompressoren zum Betrieb der Transitleitung für Erdgas 490 TJ (2017: 470 TJ)
[6] Sonne, Wind, Biogas, Biogene Treibstoffe, Umweltwärme; Quelle: Statistik der erneuerbaren Energien, BFE

[1] légères différences possibles par rapport aux combustibles pétroliers dues à l'arrondi
[2] source: Statistique suisse de l'électricité
[3] chemins de fer (y compris chemins de fer de montagne, téléski, trams, trolleybus ainsi que pertes des caténaires)
[4] correspond à la consommation finale de l'agriculture
[5] dont consommation de gaz des compresseurs de la conduite de transit: 490 TJ (2017: 470 TJ)
[6] soleil, énergie éolienne, biogaz, carburants biogènes, chaleur ambiante; source: Statistique des énergies renouvelables, OFEN

BFE, Schweizerische Gesamtenergiestatistik 2018 (Tab. 17)
OFEN, Statistique globale suisse de l'énergie 2018 (tabl. 17)

Final Energy Consumption of Switzerland 2018