The Future of the Swiss Transmission Grid

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Abstract

The Swiss utility industry would like to expand and upgrade Switzerland's high voltage transmission grid but environmental groups are opposed. We analyzed alternative perspectives on the need for upgrades, the technologies available, and the regulatory approval process for new lines. Based on a series of interviews with representatives from the utility industry, government agencies, environmental groups, and other experts, we presented means to safeguard and streamline future grid upgrades and recommend that the different stakeholders work together as early as possible in the planning process of new lines. We also recommend that Swissgrid explore using a partially underground system and more visually appealing overhead towers to address public concerns about aesthetics and health.

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Executive Summary

After the blackout in Italy and Switzerland in 2003, European countries have been trying to increase the stability and security of their electric transmission grids. With the phasing out of nuclear energy, Switzerland is looking to use more new energies to replace the void filled by nuclear power. We believe this is the perfect time to assess the major concerns stakeholders have with the future of the grid, and to make changes to ensure the efficiency of the grid. This report analyzed the need for upgrades in the electrical transmission grid, compared the technologies that can be used to upgrade the system, and assessed the regulatory process for approving new lines in Switzerland. The report proposed methods to ensure the future electrical grid is reliable and meets everyone's needs.

With the aging infrastructure, pressure to move toward renewable energies, and modern electricity demands, the utility industry believes the current transmission grid in Switzerland is in need of upgrading and expansion. There is opposition to upgrades and expansions, however, because while people want electricity in their homes, they do not want to see the power lines or to be affected by potentially unhealthy electro-magnetic fields. Swiss land is very valuable, and large towers and starkly visible transmission lines decrease this value significantly. To reduce or avoid this visual impact, the system can be put underground. The cost of undergrounding a transmission line is very high, however, usually amounting to more than four times more expensive than an equivalent overhead line. Contrary to the views of the utility companies, many people and environmental groups prefer this option more than overhead transmission lines. This sparks a debate between Swissgrid, the transmission system operator in Switzerland, and the affected people. On one hand, an underground system is very costly; on the other hand, overhead lines detract from an otherwise beautiful landscape and reduce land value for those living nearby.

After conducting several interviews, we realized that the debate on upgrading and expanding the grid is not as clear cut as we thought. The different stakeholders are in agreement that the grid will continue to need upgrades and maintenance. As for expansions, the different stakeholders disagree on the amount of expansion needed and which energy sources should pave the way for the future of the grid.

Swissgrid and the utility companies want major upgrades to the grid in order to replace aging infrastructure, meet the growing demand for energy in Switzerland, and improve the reliability of the grid, especially given its role as the crossroads of electricity distribution throughout Europe. On the other hand, environmental groups believe that instead of investing in the growth of the grid, Switzerland should invest in moving towards a decentralized power system. They are currently discussing the possibility of increasing incentives to switch to photovoltaic (PV) power with the Office of Energy. Environmental groups are also pushing for conservation of energy by increasing electricity prices to decrease demand and the need for upgrades. They are, however, willing to accept upgrades when they are essential for the continued operation of the grid. The Office of Energy is currently working on changing the energy policy, including the introduction of more decentralized power sources to the system. Based on these findings, we recommend that the Office of Energy and other appropriate agencies work with Swissgrid, the utility industry, environmental groups and other interested and affected parties to work together to approve the changes in a timely fashion.

There is also considerable debate about which technology to use for electric transmission systems. From our background research and interviews, we have concluded that there are definite advantages and disadvantages between underground and overhead lines, depending on the assumptions made and the particular concerns of different stakeholder groups.

The utility companies and Swissgrid prefer to use overhead lines because they are an established technology and more cost effective than underground lines. Environmental groups and individuals living close to transmission lines prefer underground systems, because they have less visual impact and are presumed to be safer for the nearby residents. Using a partially underground system might be a good compromise between the two sides. We recommend that Swissgrid looks into using a partially underground system for all of their lines, undergrounding sections that pass through sensitive areas. Since the main concern of using overhead lines is the aesthetic impact on the landscape, we also recommend that Swissgrid looks into developing more visually appealing towers for the overhead infrastructure.

The Office of Energy currently has criteria to help utility companies, Swissgrid and environmental groups decide on which is the best option for new transmission lines. These criteria, however, are only used to develop an argument and the different stakeholders are not required to take them into consideration when making final decisions. We recommend that the Office of Energy sets a standard for using overhead and underground systems. We recommend revisiting these standards and technology options as technologies and specifications change. Another consideration is to come up with a new policy regarding overhead and underground systems. The Netherlands puts a cap on the total length of overhead lines for both the transmission and distribution levels of their grid. Every new overhead line built must be compensated by burying an equal length at a different location. This approach has led to the speedy planning and implementation of many transmission lines due to minimal opposition. We recommend that the Office of Energy works with Swissgrid and the other stakeholders to look into a similar policy and find a compromise that will please each involved group in Switzerland.

Another problem slowing down grid expansions is that the process for building new lines often takes between fifteen and twenty five years to complete. If the technology and other factors change during that period, the utility companies or Swissgrid might need to restart the projects from scratch or make extensive changes which will cause further delays in the new lines. Swissgrid is proposing procedural changes that will speed up the process and make it easier for them. The new process allows individuals to oppose the new lines in the Cantonal Court before the Office of Energy approves the new line. After the court's decision and once the Office of Energy approves the project, no one will be able to oppose it. The environmental groups oppose the speeding up of this process, as it currently gives them enough time to raise opposition. They believe the current process allows time for Swissgrid to put extensive thought into the lines they want to build. Another worthy point is that Swissgrid is currently trying to include environmental groups and stakeholders early on in the process to avoid opposition afterwards. This is favorable for Swissgrid, reducing the time to build lines by a few years at least. We recommend that Swissgrid includes stakeholders in both the Energy Strategy 2020 and 2050 plans, which would allow environmental groups to express their concerns years before some of the lines start their approval process.

The Office of Energy is proposing changes that will make the process quicker, easier, and more transparent for the stakeholders involved. It hopes to help speed up the approval process without restricting the rights of opposition groups. For these reasons, we recommend that

Swissgrid and the Office of Energy work with the opposition groups to find a compromise to speed up the system without limiting the period of opposition.

Authorship

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Acknowledgements	A.O.	A.O.
Executive Summary	All	All
1 Introduction	S.M., A. O.	All
2 Literature Review	All	S.M., A.O.
2.1 Literature Review Introduction	A.O.	All
2.2 Electricity production and consumption in Switzerland	A.O.	S.M., A.O.
2.3 Creating a Modern Grid	S.M.	All
2.4 Overhead vs. Underground	A.A.	All
2.5 Planning Approval Procedure	A.A.	S.M., A.O.
2.6 Literature Review Conclusion	S.M.	A.O.
3 Methodology	All	S.M., A.O.
4 Findings	A.A.	S.M., A.O.
5 Conclusions and Recommendations	A.A.	All
5.1 The Future of the Grid	A.A.	All
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5.3 Process for Building New Lines	A.A.	All
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1 Introduction

For many experts and stakeholders in Switzerland, the upgrading and expansion of the transmission system is a critical task. The necessity and urgency is growing because some transmission lines are almost 40 years old and demand for electricity is straining the capacity of the current transmission grid. Additionally, redundancy within the grid ensures steady, reliable power provided to the customers. Without the expansion, grid congestion is likely to increase, making it more difficult for available supplies to meet demands and large power outages are likely in the case of a natural disaster. The aging infrastructure, increased electricity demands, and continued desire for uninterrupted power means there is an urgent need for a newer, more extensive and flexible electrical grid. Other stakeholders, especially environmental and local citizen groups, believe major upgrades are not necessary and the Swiss government and utility companies should instead focus on making the grid more amenable to distributed sources of renewable energy, such as photovoltaic panels.

Either way, upgrading the Swiss transmission grid, which is a central part of the larger European grid, presents enormous technical and political challenges. One of the key decisions facing Switzerland and its European neighbors is whether to upgrade the grid with underground or overhead transmission lines, or a mix of both. Overhead transmission lines are accepted as the cheapest option, and can range from roughly two to ten times less costly than an underground cable depending on the situation. Unfortunately, nearby residents can see the large overhead structures cutting through the landscape and have raised concerns about potential adverse health effects. Underground cables can be installed out of sight, but can cost much more in terms of installation and operation. The primary goal of this project was to compare the advantages and disadvantages of upgrading the electrical transmission system in Switzerland using underground versus overhead options. We examined a variety of technologies, including Gas Insulated Lines (GIL) and cables, and solicited the opinion of a wide variety of experts and stakeholders.

We interviewed experts from various electric, utility, and distribution companies to evaluate the need and options for an upgraded energy transmission system in Switzerland. We also interviewed government officials, academic and industry experts, and representatives from citizen and environmental groups to identify likely obstacles and possibilities for overcoming them. Using the data from these interviews and other supporting documentation, we provided an analysis of the different options and present an informed recommendation about possible courses of action.

2 Literature Review

2.1 Introduction

To achieve our goal we conducted extensive research on the electric grid in Switzerland and on the debate about overhead vs. underground systems. Before we could compare the different technologies that can be used for the grid upgrades and expansions, we had to understand how electricity is produced and moved around Switzerland. Then we needed to look at the different technologies that can be used for new transmission lines and for grid expansions. Lastly we looked at the complex process to build new lines in Switzerland and how the process affects the future of the grid.

2.2 Electricity production and consumption in Switzerland

2.2.1 Primary Sources of Electricity

Switzerland generates 57% of its electricity from hydropower, 40% from nuclear, and less than 3% form other renewable energy, such as solar, wind, and biomass (see Figure 1). Given the high levels of annual precipitation and snowmelt as well as the mountainous terrain, hydroelectric power plants have historically been a mainstay of power production in Switzerland (SFOE, 2014). There are 556 hydroelectric power plants in Switzerland that have a capacity of at least 300KW that generate about 35,500 GWh per year on average. Two-thirds of all hydroelectricity is generated in the mountainous cantons of Uri, Grisons, Ticino and Valais, while Aargau and Bern also generate significant quantities. Ten percent of Switzerland’s hydropower generation comes from facilities situated on bodies of water along the country's borders (SFOE, 2013).

Switzerland's Energy Generation

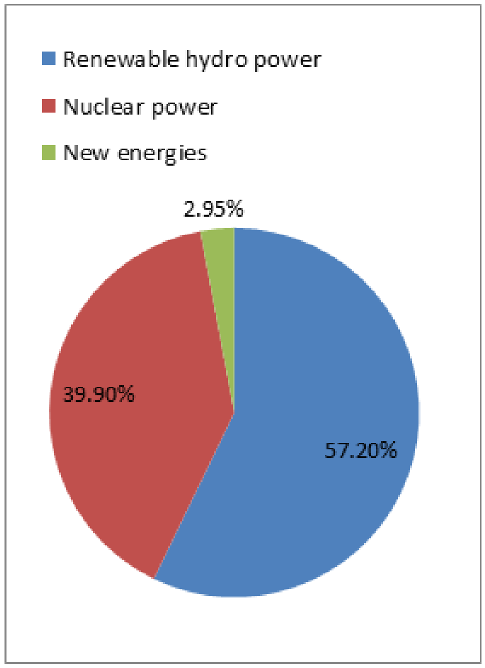

Figure 1: Swiss Energy Generation Breakdown (Swiss federal Office of Energy, 2012)

Table 1, below, shows several of the hydroelectric power plants in Switzerland. Many of these are used as pump energy storage, which means that when there is an excess of power, it is used to pump water uphill into a reservoir to be reused later. This process essentially "recharges" the station during times of excess power, and "discharges" it when electricity is needed most. Using the extreme elevation changes in the Alps, these hydroelectric plants are incredibly effective which explains why so much electricity is produced (Energy Market Price, 2013). A hydroelectric plant rarely operates at its full power rating over a complete year. The ratio of annual average power to installed capacity rating is the capacity factor. The units of the hydroelectric capacities are in megawatts. It is shown in Table 1, that Kraftwerke Hinterehein AG and Maggia Kraftwerke AG have the highest capacities; whereas, Aarewerke and Energie Electrique du Simplon SA have the lowest capacities.

Hydroelectric power stations in Switzerland

Company	Capacity MW	Power generation GWh average
Aarewerke	43	221
Atel Hydro AG	96	555
Atel Hydro Ticino SA	60	100
Blenio Kraftwerke AG	500	860
Electra-Massa AG	340	555
Electricite d'Emosson SA	360	865
Energie Electrique du Simplon SA	42	239
Engadiner Kraftwerke AG	410	1338
Kraftwerke Gougra AG	159	560
Kraftwerke Hinterrhein AG	651	1400
Kraftwerk Ryburg-Schworstadt AG	110	705
Kraftwerke Zervreila AG	250	527
Maggia Kraftwerke AG	626	1365

Table 1: Hydroelectric Power Stations in Switzerland (Energy Market Price 2013).

The second biggest producers of electrical power are the nuclear power plants located in the northern regions of the country. Table 2 summarizes the five operational nuclear power plants operating in Switzerland and Figure 2 shows that they are concentrated in the northern part of the country where the land is less mountainous, water is in good supply, and energy demands are higher. The nuclear plants opened between the years of 1969 and 1984. Beznau 1 and 2, Goesgen and Leibstadt are located in the north-central part if Switzerland; and Muehleberg is located in the western half of the country (NRC, 2012).

Status of Swiss nuclear power plants					
	Grid date	Type	Capacity (MW)	Production (2010)	Utilization
BEZNAU-1	1969	PWR (pressurized water reactor)	365	3 045 GWh	95.80%
BEZNAU-2	1971	PWR (pressurized water reactor)	365	2 894 GWh	90.50%
GOESGEN	1979	PWR (pressurised water reactor)	970	8 087 GWh	96.10%
LEIBSTADT	1984	BWR (boiling water reactor)	1165	9 437 GWh	92.50%
MUEHLEBERG	1972	BWR (boiling water reactor)	355	2 894 GWh	92.60%

Table 2: Nuclear Power Plants in Switzerland (Energy Market Price, 2013).

Figure 2: Nuclear Power Plants in Switzerland (SwissInfo, 2013).

Capacity factor is a measure of how often an electric generator runs for a specific period of time. It compares how much electricity a generator actually produces with the maximum it could produce, given continuous full power operation during the same period (EIA, 2013). It is noted that Leibstadt has the most capacity, in megawatts, while the production is measured in gigawatts per hour. Again, Leibstadt produces about three times more energy than the other power plants, but the utilization is approximately the same for all five nuclear power plants (Nuclear Regulatory Commission, March 2012). There are two types of nuclear energy reactors, pressurized water and boiling water. Despite slight technical differences between these two reactor types, the end result is the same.

In Switzerland, nuclear power supplies just under 40% of the electricity used domestically. These plants are aging, however, and Switzerland is slowing trying to phase out nuclear energy in favor of other sources of power. Following the decision taken in 2011 by the Federal Council and Parliament to withdraw from nuclear energy, Switzerland's electricity supply system will have to undergo major changes in the near future. The existing nuclear power plants are to be decommissioned when they reach the end of their lifetime in terms of operational safety, and will not be rebuilt or replaced by new ones. Switzerland voted to reject extension of nuclear energy, and nuclear power is expected to gradually be removed from the power grid starting in 2020 (BBC, 2014).

Within the scope of a new energy strategy3, the Federal Council is focusing on a higher degree of energy efficiency and the expansion of renewable energy use in order to guarantee a secure electricity supply. The Swiss Federal Council has developed the long term energy policy called the Energy Strategy 2050 based on the revised energy perspectives. At the same time, it has produced an initial set of measures aimed at securing the long term energy supply. This new strategy focuses on the renovation, expansion and modification of the country's electricity networks, and on promoting energy research and international cooperation in the energy sector. The decision to phase out nuclear energy is of strategic importance, and providing a clean, economical, and climate-friendly supply of energy is a major challenge. The initial stages of the plan focus on the consistent use of the existing energy efficiency potentials, as well as on the potentials of hydropower and new renewable energy sources (CSS, 2012).

Under the Energy Strategy 2050, the federal government plans to greatly reduce and stabilize per capita electricity consumption as of 2020. The share of fossil energy is to be reduced and nuclear electricity generation will be replaced by an increase in efficiency and the use of renewables, as well as the addition of incentives promoting the use of renewable energies (Fueeg, 2013).

Figure 3 shows the Swiss Federal Office of Energy's plan to change the mix of electricity generation, while Figure 4 shows the projected growth of renewable energies as stated in the Energy Strategy 2050 (CSS, 2012).

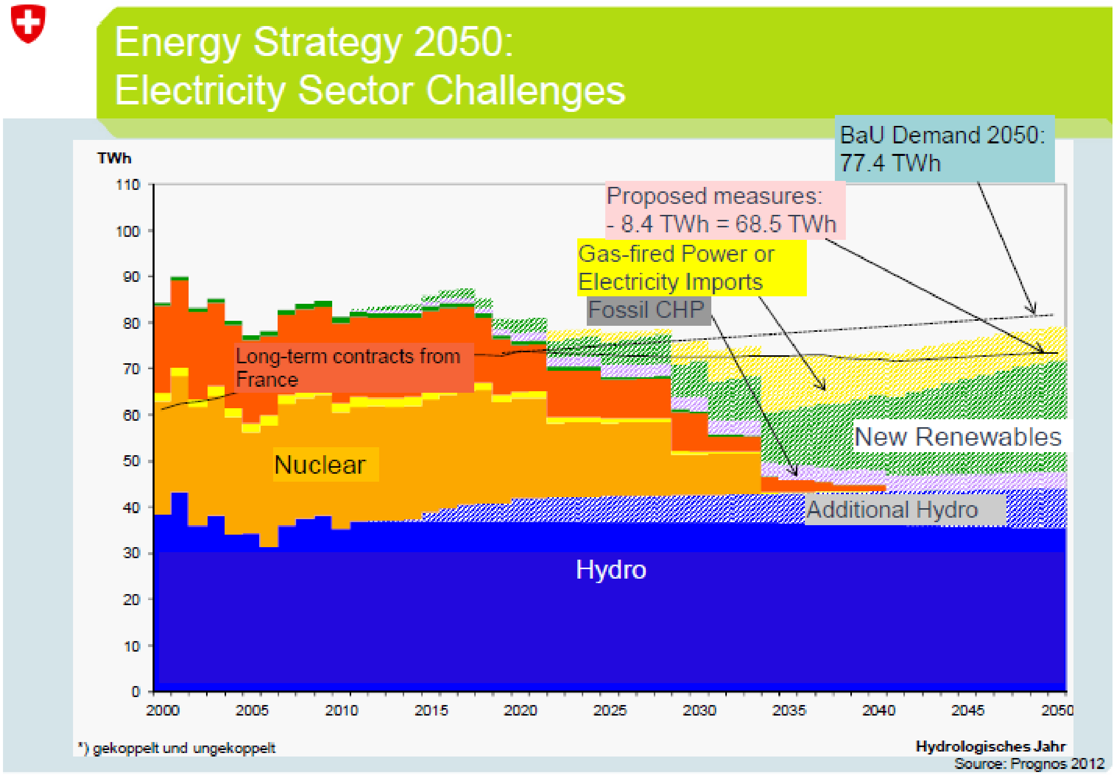

Figure 3: Electricity Trends of Energy Strategy 2050 (Fueeg, 2013)

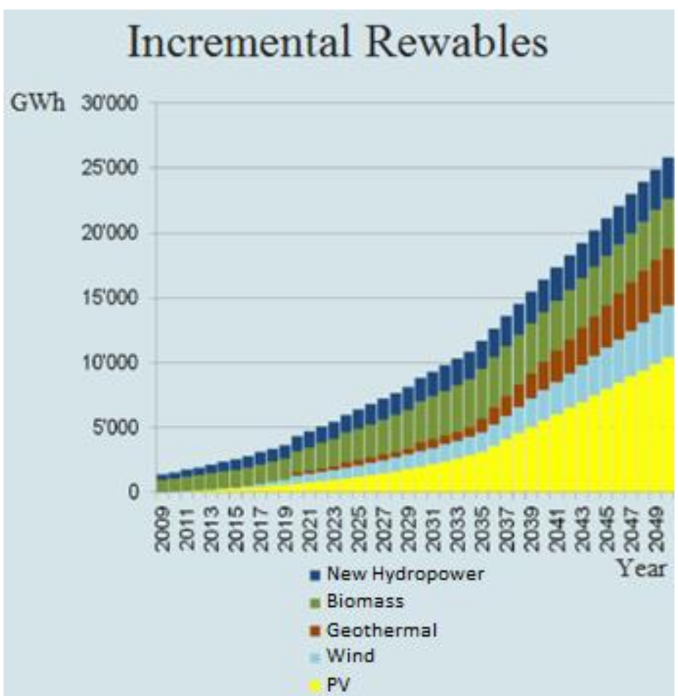

Figure 4: Projected Trend in Renewable Energy (Fueeg, 2013)

In past years, new renewable energies have not been a prominent source of power for Switzerland, but are set to supply more energy in the future. Clean energies are popular with the government and citizens alike and are being actively encouraged with government subsidies paid to solar, wind and thermal energy producers. Under the Energy Strategy 2050, the government hopes to expand other renewable sources, especially solar and wind. Solar energy in Switzerland currently only accounts for 0.04% of total energy production (shown in Figure 5), due in part to the fact that the cost of solar energy is significantly higher than other sources. As these costs come down, however, this technology will likely become more competitive on the market (Country Reports, 2014).

Solar radiation can be used as a valuable source of energy within a household or company building. This energy can be photovoltaic, i.e. converted into electricity with the excess either stored in a battery or fed back into the grid, or solar heat panels which can be used for domestic heating. When used on a local scale, photovoltaic (PV) panels can be quite effective at providing power to a community. In areas where population densities are very high, however, it is often very difficult to provide for everyone’s needs using only PV. Ambient and geothermal heat found in the air and ground can also be converted into usable domestic heating via heat pumps. These pumps require an electricity source to run, but present a more efficient and environmentally friendly use of resources than traditional oil-fired heating, and are becoming a popular feature in new residential buildings in Switzerland (Jorio, 2012).

Switzerland also has a few large wind farms, and wind energy is seen by the Swiss government as having great potential for future expansion. Of course this is not without controversy, and there are now clear and specific rules on where a wind farm may be located, with a focus on effectively marketing wind power to pave the way for increased production. Another cleaner fuel source which is being developed and promoted is the use of biomass, such as wood or food bio-waste. Switzerland has not yet taken up usage of this type of heating to the same extent as Austria, Italy, and other neighboring countries, but the 2050 plan expects this percentage to grow (Jorio, 2012). Currently waste to energy is the largest of the new energy sources, as seen in Figure 5.

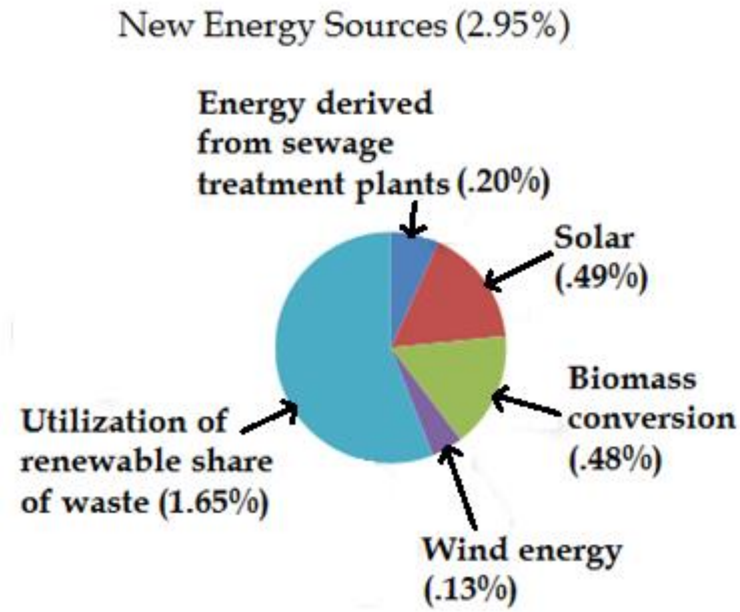

Figure 5: Current Swiss Energy Generation (Swiss Federal Office of Energy, 2012)

2.2.2 Overview of the Swiss Electric Utility Companies

Swissgrid is the transmission system operator (TSO) in Switzerland, and is affiliated with the European Network of Transmission System Operators for Electricity (ENTSO-E). Swissgrid was established in January 2005, and transports electricity at the highest voltages used in the country. Since it owns and operates the transmission system in Switzerland, Swissgrid guarantees that the high voltage grid is secure, reliable and cost efficient. As a member of ENTSO-E, it is also in charge of the exchange of electricity in Europe passing through Switzerland on the intercontinental transmission grid (Swissgrid, 2014).

Swiss Grid is organized as a corporation and its legal form is a joint stock company. Swissgrid is owned by 21 Swiss electricity companies. These companies are directly or indirectly majority-owned by the cantons and the municipalities. Although the combination of all the electric companies that own shares in Swissgrid make up the whole Swiss electric There are five main Swiss electric companies shareholders, including Axpo, BKW, Alpiq, BKW, and Repower as shown in Figure 6 (Swissgrid, 2014).

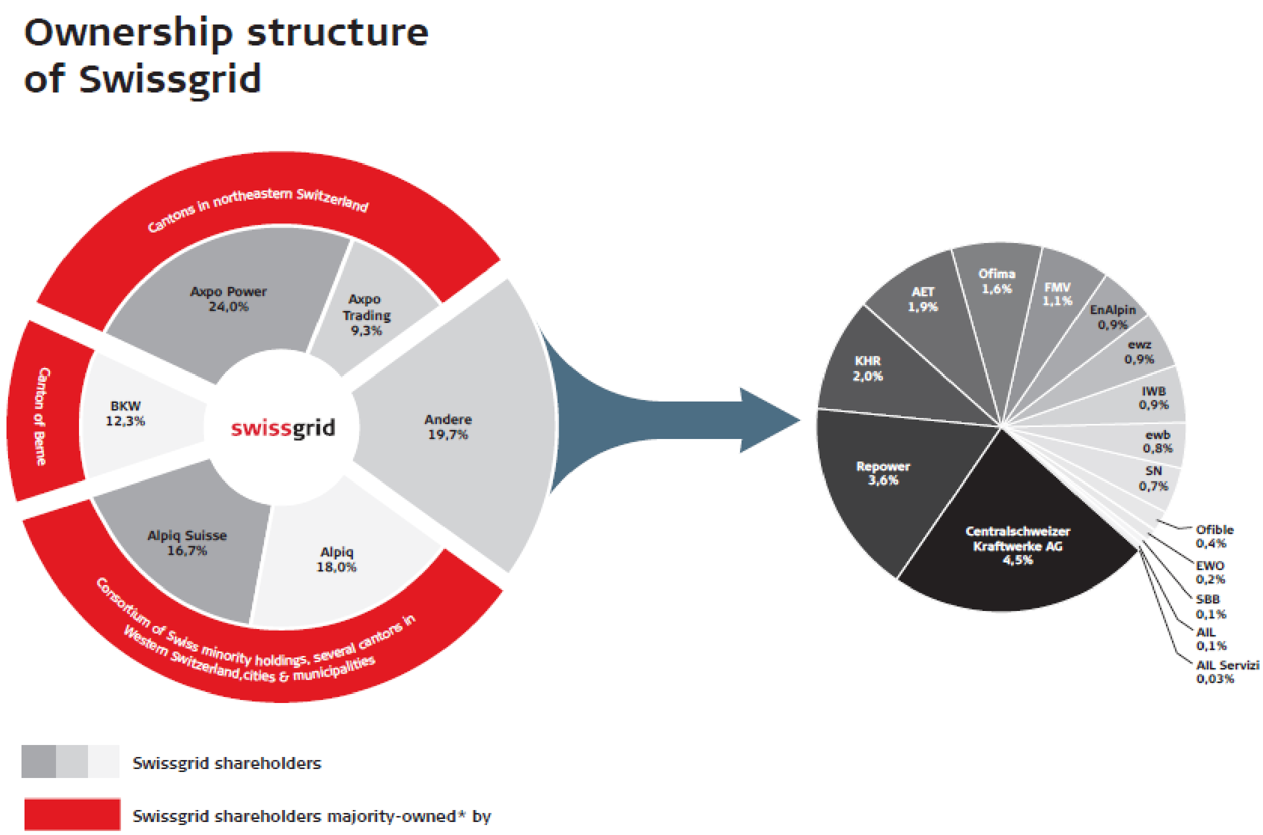

Figure 6: Ownership of Swissgrid by percentage of different shareholders (Swissgrid, 2014).

These different electric companies are responsible for generation of the power that feeds into the grid. As shown in Table 3, each has a particular geographic focus and a different mix of generating sources, including nuclear, hydro, thermal, solar, and wind energies.

Company	Canton	Hydro	Nuclear	Thermal	Solar	Wind	Gas
Axpo	Aargau	64%	30%	2%	4%	0%	0%
Repower Energy AG	Graubunden	52%	14%	0%	0%	5%	29%
BKW Energie AG	Berne	35%	52%	4%	6%	4%	0%
EWZ	Zurich	73%	21%	0%	6%	0%	0%
Alpiq AG	Vaud	28%	29%	40%	1.5%	1.5%	0%

Table 3: Major Swiss Companies (SwissInfo, 2014)

Figure 7 shows the total installed generating capacity for each company and the relative contribution by different sources. It is noticeable that Axpo and Alpiq have the most installed electrical power.

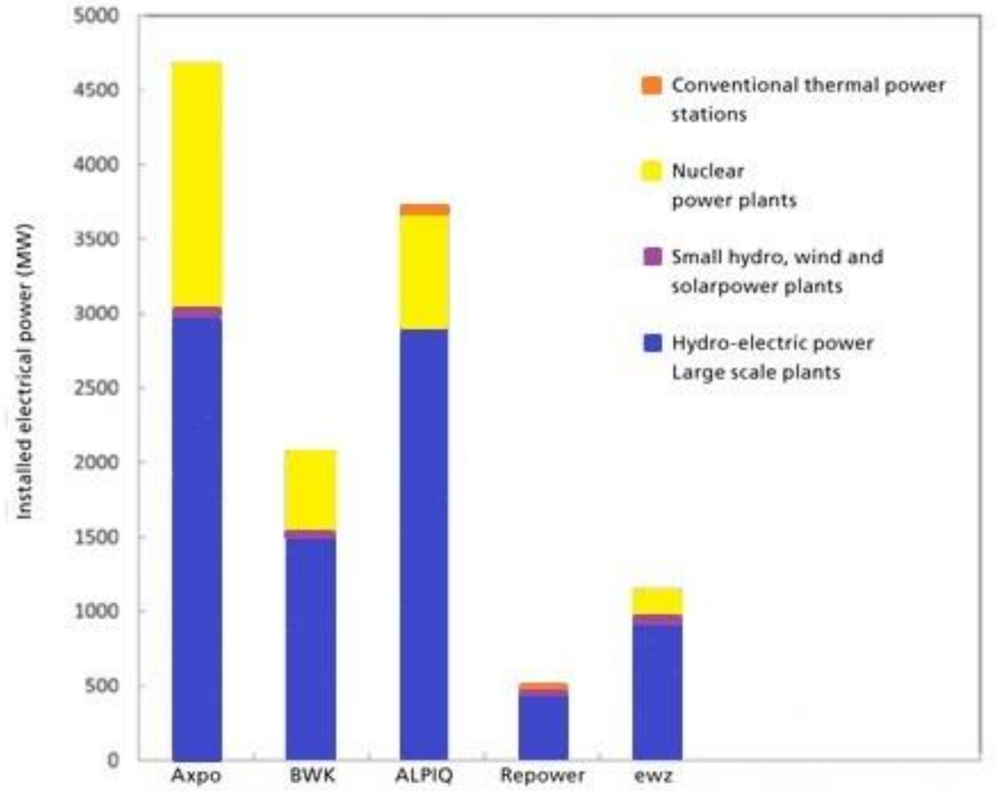

Figure 7: Installed Generating Capacity by Company and Power Source (Pauli, 2013).

Axpo AG is an energy utility company with its operational headquarters in Baden, Switzerland, and is one of the largest Swiss companies by revenue. Axpo Holding AG primarily engages in the generation, transmission, distribution, and supply of electricity in Europe and internationally, as well as the trade and procurement of several other energy commodities (Bloomberg Business Weekly, April 2014).

Ratia Energie AG (Repower Energy) is one of Switzerland's oldest energy companies, mainly operating in the Canton of Graubünden, in the Northeast, and in several municipalities in Western Switzerland. The group operates from generation and trading to sales. The Canton of Graubünden holds almost 60% of its shares, but Axpo Holding, the group that owns Axpo Power, comes close with a 35% share in the company.

BKW Energie AG is a power production and distribution company, another one of the largest and oldest in Switzerland. BKW covers almost all stages of energy supply, from production to trading and distribution. BKW generates power for the canton of Berne. The majority of BKW's energy is produced from nuclear and hydroelectric power plants, but BKW also owns two wind farms, one in Switzerland and one in Germany. BKW is also a leading supplier of solar energy and biomass (BKW, 2014).

Elecktrizitatswerk der Stadt Zurich (EWZ) is one of the top ten utility companies in Switzerland, supplying power mainly to Zurich and the Zurich canton. EWZ is heavily invested in promoting and developing new renewable energies, outlined in Table 3 (EWZ, 2014). EWZ is also investing abroad in countries such as Norway and Germany by acquiring wind farms in those areas.

Alpiq AG is one of the leading energy companies in Switzerland, with over 4000 employees and over 80 locations around Switzerland and Europe. Alpiq generates power for several cantons in Western Switzerland, and makes systematic use of renewable energies, while reducing CO2 emissions with CO2-neutral plants. Alpiq produces energy from hydropower, wind and solar energy, geothermal energy and biomass (Alpiq, 2014). Alpiq specializes in the production, distribution and trading of electric power, and on January 3, 2013, transferred its ultra-high voltage transmission grid to Swissgrid. Swissgrid is taking charge of expanding the transmission grid by incorporation Alpiq's lines (Apliq, 2013).

These are some of the main shareholders of Swissgrid. Collectively, these and other smaller companies are responsible for the generation and distribution of power in Switzerland, but Swissgrid itself is responsible for the high voltage, long distance transmission.

2.2.3 The Swiss Transmission Grid

Swissgrid operates the Swiss transmission system and is in charge of the operation, security and the expansion of the high voltage grid. The Swiss transmission network is about 6700 km long and operates at voltages of 220 kilovolts and 380 kilovolts and a frequency of 50 Hertz. Electricity cannot easily be stored so production and consumption have to be balanced throughout the transmission system. The Swissgrid electricity marketplace guarantees a balance between electricity producers and consumers, and incorporates feeding electricity generated from renewable sources back into the grid (Swissgrid, 2014).

Figure 8 is a map of the current high voltage transmission system in Switzerland, as of 2014. The red lines represent 380 kV sections, the green lines represent 220 kV transmission lines, and the red circles are the substations (Swissgrid, 2014).

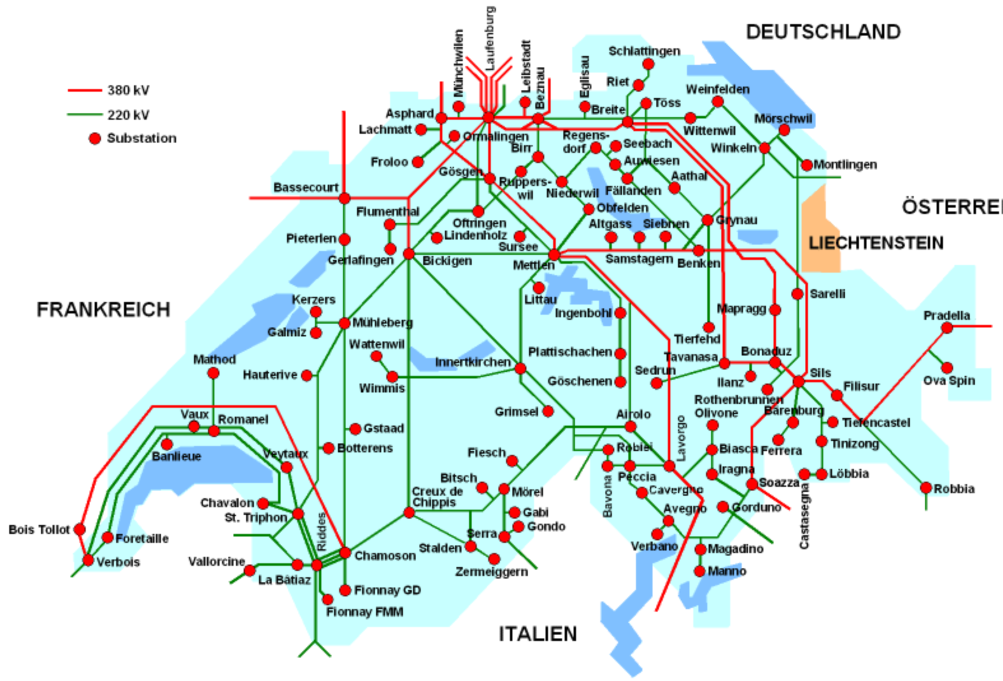

Figure 8: Swiss National Electrical Transmission Grid (GENI, 2014)

The Swiss electricity grid is divided into seven grid levels. They are numbered 1 thorough 7 as shown Figure 9. The transmission system includes the extra-high voltage and the high voltage levels, labeled #1 and #3. The distribution system includes the medium voltage and the low voltage levels, which are numbers 5 and 7. The transformers are #2, #4 and #6, and raise and lower voltages between the different levels.

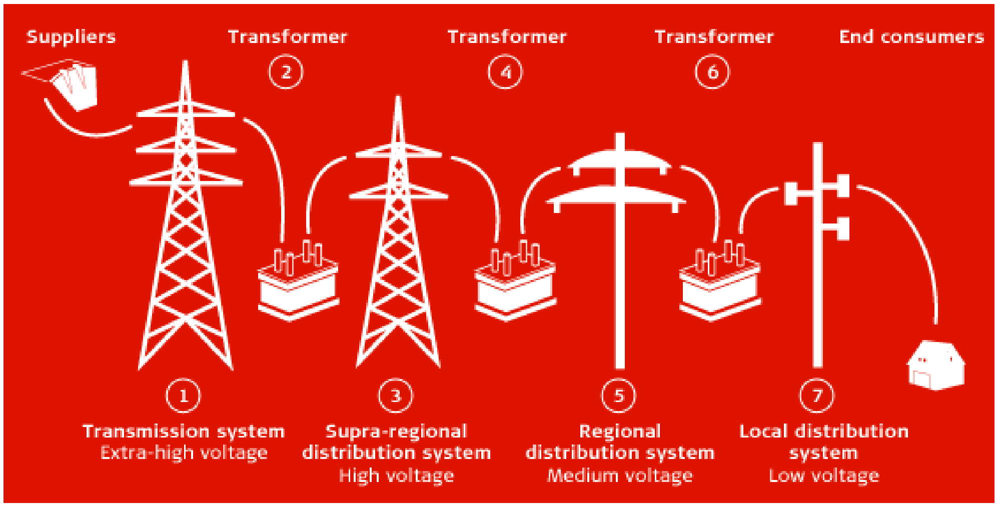

Figure 9: Different grid levels and transformers of Swissgrid (Swissgrid, 2014).

The transmission grid absorbs the electricity produced by the large power plants or from other countries, and is transported at Level 1 (380 kV or 220 kV) to be later fed into the lower level distribution grids for shorter, more local distances. The supra-regional distribution system supplies electricity at high voltage (50 to 150 kV) to cantonal, regional and public distribution grid operators and to major industrial plants. The regional distribution system supplies power at medium voltage (10 kV to 35 kV) to individual suburbs or villages and small and medium sized industrial organizations, while the local distribution system operates at low voltage (400 V or 230 V) and supplies individual homes and businesses. Transformer stations connect the different systems and step the voltages down to meet the system requirements (Swissgrid, 2014).

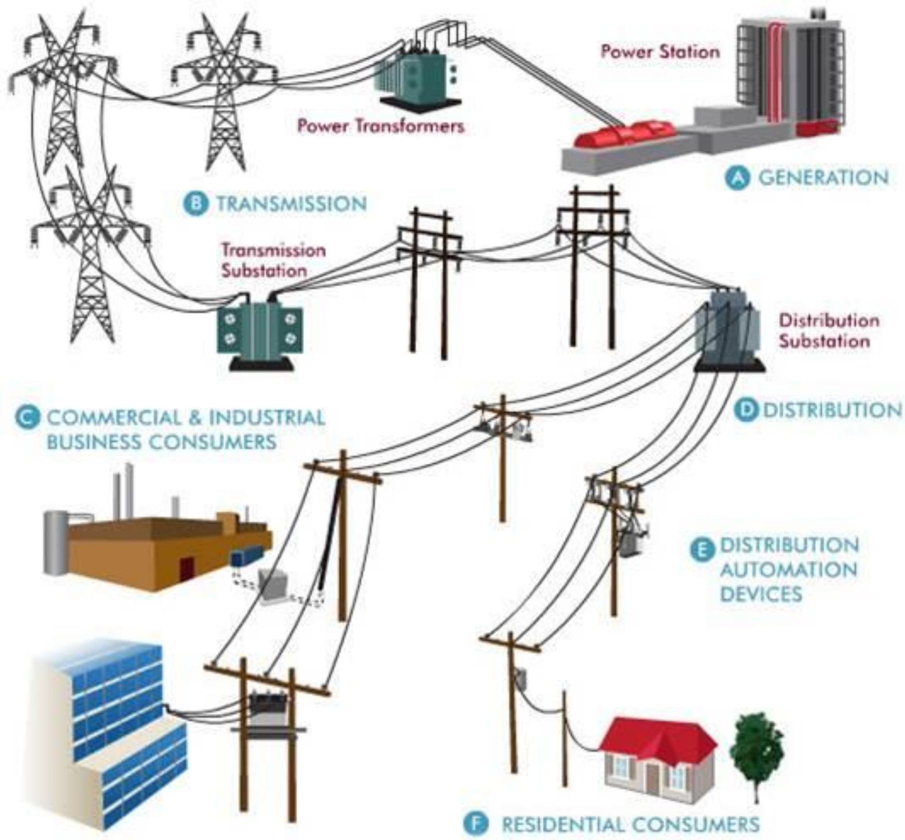

Figure 10: Flow of Electricity (Bravo Projects, 2013).

Figure 10 is a more detailed representation of the process of transporting electricity from the source to the consumer. The figure graphically shows both the transmission and distribution lines.

Swissgrid is continuing to work on expanding the grid as part of their 2020 strategic grid plan. The 2020 grid plans to eliminate existing and projected bottlenecks in the transmission grid, which are expected in the context of the planned changes of power plants. Allowances have been made here both for the pumped storage power plants already under construction as well as those newly planned. The 2020 strategic grid was coordinated and agreed upon within the expansion projects of ENTSO-E, and includes approximately 52 renewal and expansion projects (Swissgrid, 2014). The three main projects that they have focused on are the Chamoson – Ulrichen, which is approximately 100 km in the Valais canton; the Chatelard – Rosel, which is approximately 22km located in the Valais canton; and the Yverdon – Galmiz, which is approximately 50km, and spans the Vaud and Fribourg cantons (Alpiq, 2013). The Yverdon –

Galmiz line has received the most opposition from the people. This line connects to the nuclear power plant Muehleberg, which is scheduled to be shut decommissioned in the near future.

2.3 Creating a Modern Grid

On September 28th, 2003, a black out affected more than 56 million people across Italy and the southern areas of Switzerland. The immediate trigger for the blackout stemmed from a fault in the Swiss transmission system. This serious power outage had immense significance to the European policy. The most serious consequences were experienced south of the Alps, but there were effects felt in Austria, France, Germany, and elsewhere in Europe. A 380 kilovolt (kV) line between Mettlen and Lavorgo was loaded to 86% of its maximum capacity, heating core temperature of the line to a point where it began to sag close to the trees nearby. As this load increased, it backed up through the transmission system, increasing the strain on the lines until they were rendered inoperable. The disruption lasted for more than 48 hours (Johnson, 2007). This created a drastic problem for the Swiss and their international exchange of energy.

When the Swiss transmission grid was initially built, on average 40 years ago, it was designed to meet the requirements at that time. Half a century later, however, these requirements have changed, and the grid can no longer support modern infrastructure and lifestyles. The grid must be upgraded continually in order to maintain reliable, steady, and sufficient power to the users whether they are within the Swiss borders or across Europe.

> *"Because of its geographical location, Switzerland is an important hub for the international trading of electricity. Hydropower plays a key role and has enabled renewable energies to enjoy a long history in Switzerland. The large number of storage power plants makes an important contribution to reliable and sustainable energy supplies in Europe. Swissgrid, an important player in Switzerland's security of supply, will be investing between five and seven billion Swiss francs in replacing and upgrading the transmission system over the next few years."*

(Swissgrid - Renewables Grid Initiative, 2014).

As the quote above illustrates, Switzerland is often described as a battery for Europe. The country buys, sells, and moves thousands of Gigawatts of electricity every year between France, Germany, Italy, and many other European countries. Because of its central location and deep involvement in European energy flows, it is crucial that there is a modern, reliable, and stable transmission system throughout all of Switzerland (Swiss Energy Statistic, 2005). Power outages like the one experienced in 2003 are unacceptable, and must be avoided. Figure 11 shows the 2005 energy movement within Switzerland. All numerical values are in GWh.

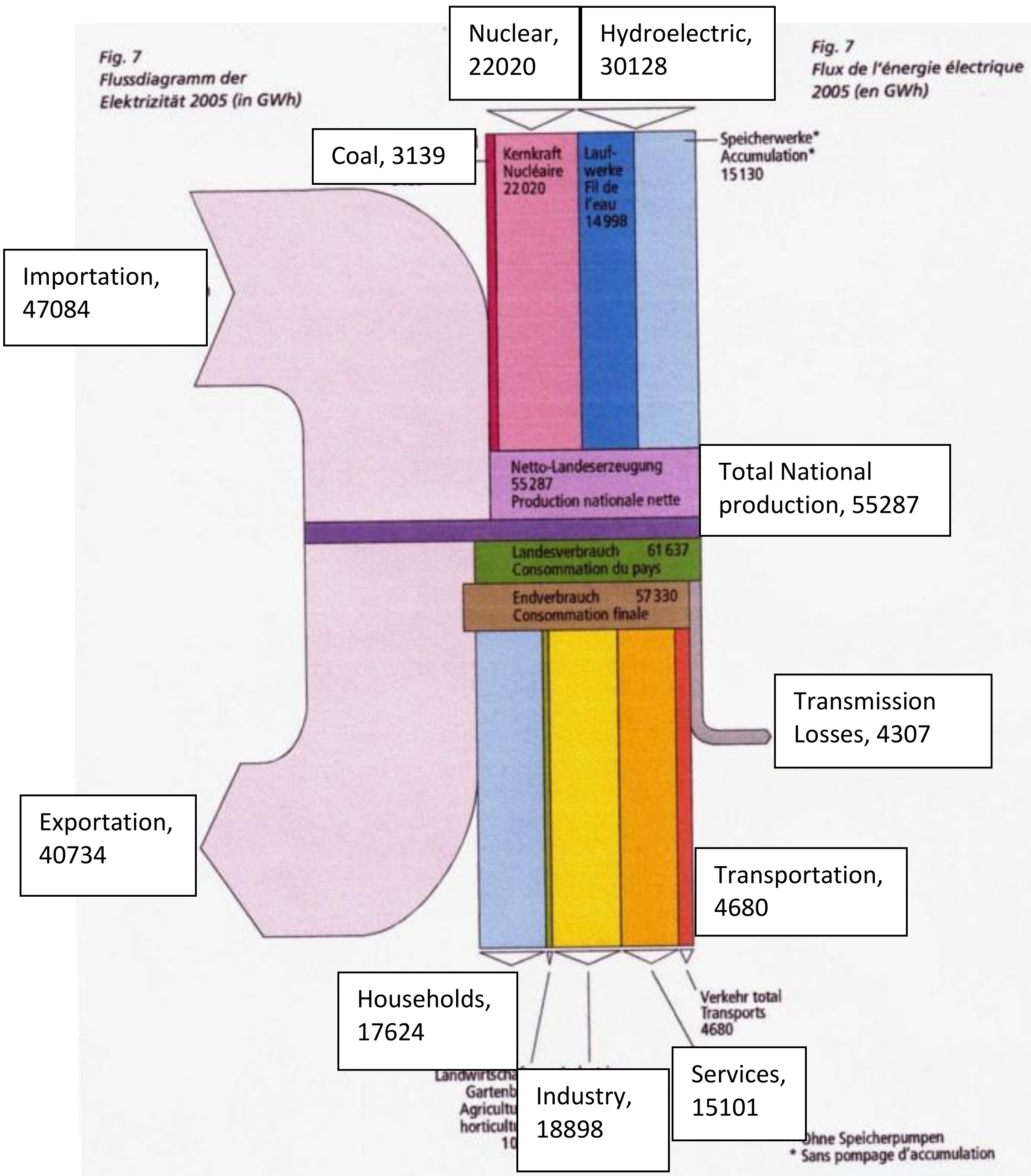

Figure 11: Swiss Energy Import/Export (Swiss Energy Statistic, 2005)

This figure clearly shows how crucial Switzerland is to the surrounding countries, and how necessary it is, both locally and internationally to have a stable transmission network. Essentially 41,000 GWh of electricity passes through Switzerland on its way around Europe. With the enormous amounts of power Switzerland imports and exports, many countries in Europe have been and will be directly affected by a bottleneck or interruption in the Swiss transmission grid.

Swissgrid has several programs in place to ensure the grid gets the proper maintenance and upgrades (Swissgrid, 2013). Figure 12 shows Swissgrid's current plan for upgrading the transmission grid.

Figure 12: Transmission System Upgrades (Swissgrid, 2013)

The lines shown in Bold represent the planned projects, with the colors representing different strategies for the grid. The most strongly prioritized projects are explained below:

- Green – the operating voltage of these existing power lines will be raised from 220 kV to 380kV. Higher voltage increases efficiency by reducing losses within the lines. This upgrade requires no additional construction as the current technology can support this voltage boost. This strategy makes up 50% of the most important projects, and is the cheapest and quickest upgrade.

- Orange – these existing routes will be bolstered, converted, and rebuilt to support modern requirements. Only 14% of the prioritized plans fall into this category.
- Blue – unlike the orange routes, the existing blue transmission lines must be completely dismantled and rebuilt from scratch for the project to be feasible. This category makes up 27% of the high importance tasks.
- Red – the lines in red show areas where no existing power lines currently exist, and must be built from scratch. This section is considerably less than the others (only 9%) and serves to fill gaps in the system, add redundancy and security, and provide power to and from new consumption centers and power plants (Swissgrid, 2013).

This plan is part of a long term strategy to help Switzerland maintain and future-proof the transmission grid. Without upgrades, the grid will continue to operate inefficiently and without the redundancy and security necessary safeguard against failures, which could be detrimental not only to Switzerland, but also to many countries around Europe. There is, however, opposition to these plans. One of the major arguments against Swissgrid's proposed plan is that people do not want large, ugly, and potentially unhealthy high voltage transmission lines in their backyards. This brings up a debate involving many different groups of people, organizations, and companies, which is whether or not to put the transmission system underground or leave it primarily overhead and in plain view.

2.4 The Debate about Overhead vs Underground Lines

One of the main debates for transmission systems is the type of system to use (Swiss Info, 2011). There are two main options that can be used for transmission systems: overhead lines and underground systems.

Overhead lines (OHL) are the backbone of the transmission grid and are employed most extensively, although underground transmission is becoming more popular for certain situations such as minimizing aesthetic impacts. Underground cables have different environmental impacts and technical requirements than overhead lines. There are two main types of underground systems: cables and gas insulated lines (GIL) (Electrical Engineering Portal, 2011).

2.4.1 High Voltage Overhead Lines (OHL)

Despite advances in the underground technology, overhead lines are still the most popular option for electric transmission systems. OHL systems use steel towers with one or more conductors per phase, supported on insulator strings. The insulator strings allow air to insulate the live conductors. Because OHL use air as an insulation medium, the size of the tower is determined by the transmitted voltage and the insulation needed. Therefore the higher the voltage, the larger the clearance distances and associated tower heights (The Grid West Project, 2013).

The OHL technology is well established. While many industry experts believe the technology presents relatively few adverse impacts, others disagree and are concerned about aesthetic impacts, potential harm to people and animals from electromagnetic fields (EMF), and other impacts to flora and fauna caused by the clearing of vegetation and the creation of access corridors. Clearing of the vegetation is also needed during the installation of underground options, but vegetation is often allowed to regrow after installation, unlike the corridors created for overhead lines (The Grid West Project, 2013).

Figure 13: Visually appealing OHL

In the past few years several projects have tried to make the OHL more visually attractive options. The projects have achieved varying levels of success and they increase the cost and the risk factor due to the unproven nature of the technologies. Figure 13 shows one such project in Japan. In the future, these designs might become a good compromise between technical, environmental, visual and economic factors playing in to the decision of using OHL (The Grid West Project, 2013).

2.4.2 High Voltage Underground Cable (UGC)

The underground system, which includes cables and GIL, has a bigger visual appeal. These systems, unlike overhead lines, cables and GILs do not use air for insulation. The conductor on the cables must be completely insulated, and the higher the voltage running through the cable the more insulation required. For GIL, the tubes are welded together with a computerized welding process to ensure no gas leaks will occur. The insulation gas is composed of 80% nitrogen and 20% SF_6. The gas is not poisonous and can be detected with ease. However, if the GIL is placed in a concealed location and a leak is not detected quickly, the gas can be deadly. (Siemens, 2014)

High voltage cables are normally single cored and are insulated by sheaths. For high voltage cables, the core is made of copper, which is one of the reasons the cables are very expensive.

When cables are used in power transmission, currents are induced in the sheath and lead to circulating currents and power loss. The currents and power loss can be reduced by cross bonding of the cables. The cable sheaths are broken at regular intervals, and bonded together as seen in Figure 14. The bonded points are grounded to prevent excessive voltage build up, especially during faults. By cross bonding the sheath the induced currents are in opposite directions, cancelling each other out and significantly improving the current rating of the cable. Transposing the cables ensures that the reactance balance out and aids in implementation (McFadyen, 2013).

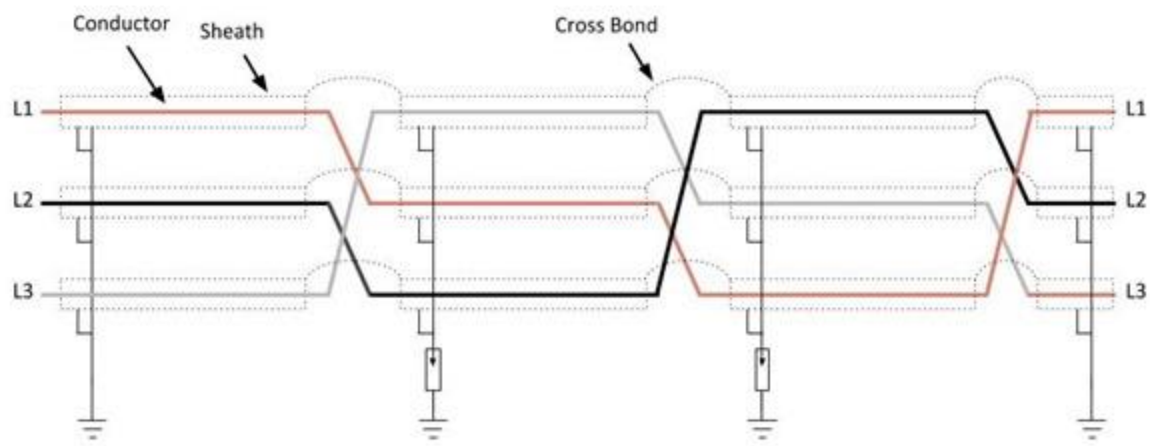

Figure 14: Transposed and Cross Bonded Cable (McFadyen, 2013)

GILs are composed of two concentric aluminum tubes. The inner conductor is placed on the insulators, which keep it centered with the outer enclosure. The outer surface is made from a strong aluminum tube, making it a strong containment. The tubes are resistive to corrosion as well (Koch, 2011).

Cables and GIL are similar technologies in term of their placement. Both technologies can be placed directly underground, in a trough or a tunnel. When placed directly underground, the cables are buried in a trench, sometimes with cooling pipes to keep the ground from heating up. Figure 15 shows the installation of a cable directly buried. Once the installation is complete, there are no visible signs of the cable along its length (EMFS, 2014).

Figure 15: directly buried cable installation (EMFS, 2014)

The cables are buried closer together in a trough, and buried in concrete flush with the ground surface as Figure 16 shows. Although the visual impact is more significant than directly buried lines, it is much less significant than OHL (EMFS, 2014).

Figure 16: Cables Laid in a Trough Near Oxford (EMFS, 2014)

Cables can also be placed in tunnels deep beneath the ground. In the past, this technique was used to bury cables beneath rivers, but it is now being used in urban areas as well. Figure 17 shows cables laid within a tunnel (EMFS, 2014).

Figure 17: Cables within a tunnel (EMFS, 2014)

2.4.3 Underground vs Overhead Comparison

There are many disadvantages and advantages for each system. The main benefit of using an underground system over an overhead system is the aesthetic benefits and lower electro-magnetic field. Figure 18 shows a comparison of the different technologies listed above.

	Overhead Lines	Cable	GIL
Capital Costs	Orange	Light Red	Red
Installation	Orange	Red	Red
Electric Magnetic Field	Red	Light Red	Orange
Losses	Red	Light Red	Orange
Capacitance	Orange	Red	Orange
Maintenance	Red	Light Red	Light Red
Operation	Light Red	Light Red	Light Red
Visual Impact	Red	Orange	Orange

Key	
Red	Least Preferred, Very High Impact, Most Expensive
Light Red	Some Impact, Some Difficulty, Medium Expense
Orange	Preferred, Limited Impact, Little Difficulty

Figure 18: A comparison between Overhead lines, cables and GIL.

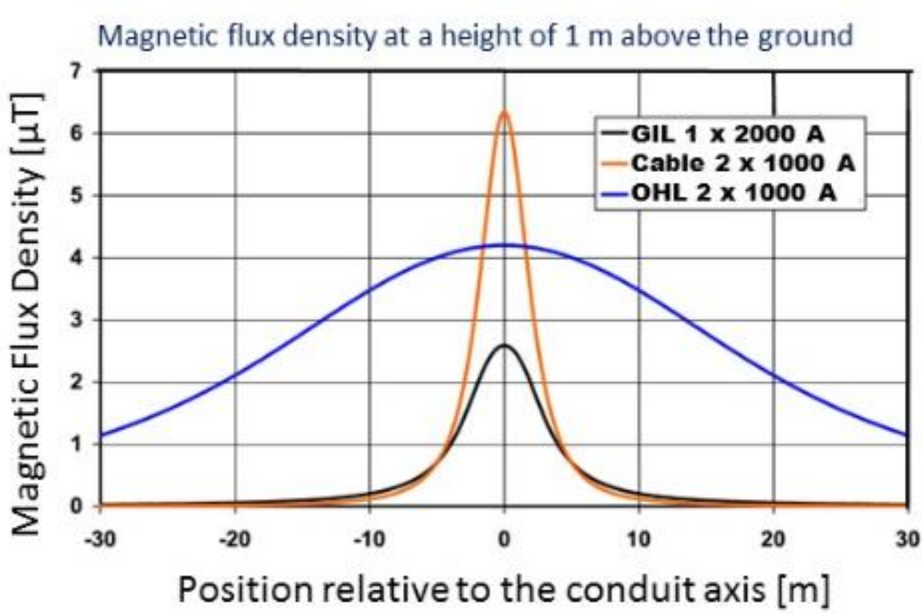

Figure 19: Magnetic Flux density comparison for OHL, Cables and GIL (EMFS, 2014)

Switzerland has very strict electromagnetic field regulations, at approximately 1µT. As you can see from Figure 19, OHL reach 1µT thirty meters away from the conductor, compared with four meters for cables and GIL. Cables have the highest EMF directly above the cable, and GILs have the lowest. In both of these underground options, however, the electromagnetic field output decline substantially with distance, while OHL has a much stronger field even at some distance. Depending on the technique used to place the cables in the ground, the EMF changes. When placed within a tunnel since the cables are buried far below the ground, the EMF falls to inconsequential amounts (EMFS, 2014).

The main problems with underground systems are their high costs. The main reason for the cost difference is that OHL require little insulation other than the air, while UGC require very precise and well-made insulation. The higher the voltage the more insulation is needed and the higher the cost for a given length of cable. Thus, on the distribution level (with significantly lower voltage), UGCs are more comparable to OHL financially. The other reason for the cost difference is that the higher the voltage, the shorter the UGC must be and more accessories are added to connect the cable segments together to cover the long distances that are required. The cables need to be shorter because of the capacitance, which causes a current to flow through the cable when no load is connected to it. The longer the cable, the higher the capacitance; and if the cable is long enough, the charging current might be equal to the limit of the cable, which will limit its ability to deliver power. OHL, on the other hand, have a much lower capacitance because the wires are farther apart and the distance to the ground is much greater (NEI, 2011).

The main advantage of GILs over cables is their high current-carrying capacities. GILs can carry very high currents for long distances without problems since capacitance is not a problem (Koch, 2011).

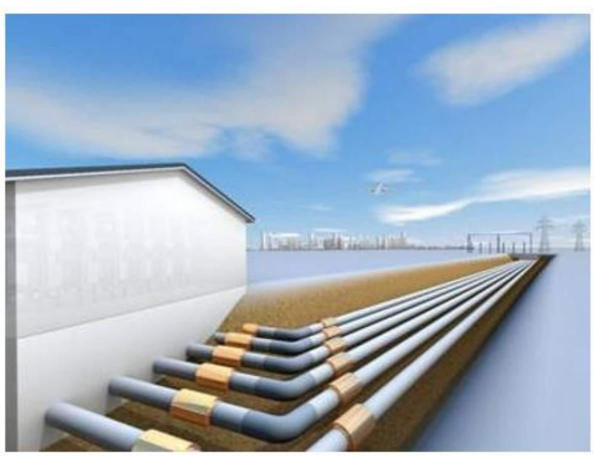

Figure 20: Image of the Gas Insulated Lines (Alpiq, 2014).

Similar to cables, GIL have a high installation cost; however, their operation costs are less than both cables and OHL. There are low resistive losses compared to cables and overhead lines. This helps to reduce the operation costs. Due to the large outer diameter, the heat disperses better with GILs than with cables, and GILs normally do not require sophisticated cooling systems. Also, because of their low capacitance, GILs do not require electrical compensation even for a system 60km and longer, and have the lowest EMF rates among the three options. The conductor current makes a reversed current of the same size in the enclosure, which results in insignificant electromagnetic field outside the GIL thus no special shielding is required (Siemens, 2014).

One of the main issues with GIL is that they have not been used extensively because of their very high costs (Siemens, 2014). In January 2012, the Institution of Engineering and Technology published a report into the costs of underground transmission systems compared with that of overhead systems. The report is being used as a point of reference for new electricity infrastructure projects in the UK and found that installing new power connections underground will always be more expensive than overhead lines on the transmission level (IET, 2012). The report claims that using ratios to compare the different technologies can be misleading because there are several ways to measure the difference in costs between different technologies. Some estimates take into account capital build costs alone, and others use life time costs. The life time costs include the build costs, operation and maintenance costs, and the power losses over a 40 year period (IET, 2012).

The report finds that capital costs vary greatly, and undergrounding typically costs about 10 times more for a given distance than the cost of installing overhead lines. The cost difference is so large primarily, because the cables themselves cost much more than the OHL. The cost of installation is also more due to the additional labor required. After their installation, however, underground cables have been proven to need less maintenance and have less energy loss. The study takes into consideration the costs of operation, periodic maintenance, and energy losses associated with each system. Table 4 shows a cost estimate of the different technologies, and how the ratio of capital build costs to total lifetime costs varies from approx. 10:1 to 5:1 (IET, 2012).

	Capital build cost - per km	Total Life-time cost (build and operation and maintenance) - per km
Overhead	£1.6m	£4.0m
Underground	£16.7m	£18.9m
Cost Difference	***£15.1m***	***£14.9m***
Ratio	***Approx. 10:1***	***Approx. 5:1***

Figures extracted from IET Report based upon 75km medium capacity circuit

Table 4: Shows the price difference for Overhead vs. cable (IET, 2012)

As mentioned earlier by changing the criteria for the comparison the price ratio will change. In a report by, Roberto Benato and Domenico Napolitano, the cost difference was compared, including the expenses of repair after random failures. The report also takes into consideration the energy losses, impact territory, capital costs, dismantling costs, UGC shunt compensation investment cost, and operation and maintenance costs. The result was a ratio of 1:2, instead of the 1:5 cited in the IET report (Benato and Napolitano, 2012).

Values of Kilometric repair costs: ((R))O, ((R))U

	OHL	Double-circuit UGC	
	All equipment	Cable	Shunt compensation equipment
(R) [€/km·yr]	704	680	1 070
	OHL	Double-circuit UGC	
((R)) [k€/km]	12,1	30,0	

Composition of overall cost [M/km]

	OHL [M€/km]	Double-circuit UGC [M€/km]
(I)	0,6	3,5
$(\Delta I)_{Sh}$	0	0,24
((E))	1,554	0,594
(T)	$0,1 \cdot w_x$	$0,018 \cdot w_x$
((D))	0,0043	0,0265
((OM))	0,052	0,035
((R))	0,0121	0,03
Σ=(I)+$(\Delta I)_{Sh}$ +((E)) +(T) +(D) ((OM))+((R))	$2,2224+0,1 \cdot w_x$	$4,4255+0,018 \cdot w_x$

The parameters involved in (1)-(2) are the following:

L [km] Route length;

n [year] Nominal lifetime of circuits;

$(I)_O$ [M€/km] OHL capital cost per kilometre (including wayleave agreements: land purchase/lease charges);

$(I)_U$ [M€/km] (XLPE) UGC capital cost (including wayleave);

$((E))_O$; $((E))_U$ [M€/km] Discounted cost of energy losses for OHL and UGC, respectively;

$(T)_O$ [M€/km] Burden per kilometre of OHL «corridor» (=F_O•10^3•w_x);

$(T)_U$ [M€/km] Burden per kilometre of UGC «corridor» (=F_O•10^3•w_x);

F [m] Width of the «corridor» along the entire line routeaccording to laws, guidelines or standards;

W_x [€/m²] Economic value of the«corridor»: average value along the link;

$((OM))_O$; $((OM))_U$ [M€/km] Discounted cost of O&M (Operation & Maintenance);

$((R))_O$; $((R))_U$ [M€/km] Discounted expected costs for repair of random failures;

$((D))_O$; $((D))_U$ [M€/km] Discounted end of life dismantling cost.

Table 5 Cost Comparison (Benato and Napolitano, 2012).

Table 5 shows the repair costs after random failures for both overhead lines and underground cables. The overall cost comparison shows a result of 1:2 which signifies a large reduction in the difference for using OHL or UGC. The Benato and Napolitano report shows that with random failures, the price for the two options becomes more comparable than it would without them (Benato and Napolitano, 2012).

Figure 21 shows the respective investment costs of underground and overhead lines based on the experience gained by transmission system operators (TSOs). The bulk of the cost is the civil work required for each installation. Over the last 10 years, the difference in range of investment costs between cables and overhead lines has been between three times and 10 times depending on voltage level and installation. Installation in underground tunnels can even be over 15 times more expensive. TSOs balance the cable's extra benefits with higher cost by partially undergrounding specific transmission network segments (Tarimo, 2011). The figure infers that the relationship of underground and overhead lines is not linear. This makes it extremely difficult to accurately compare the different technologies except on a case by case basis.

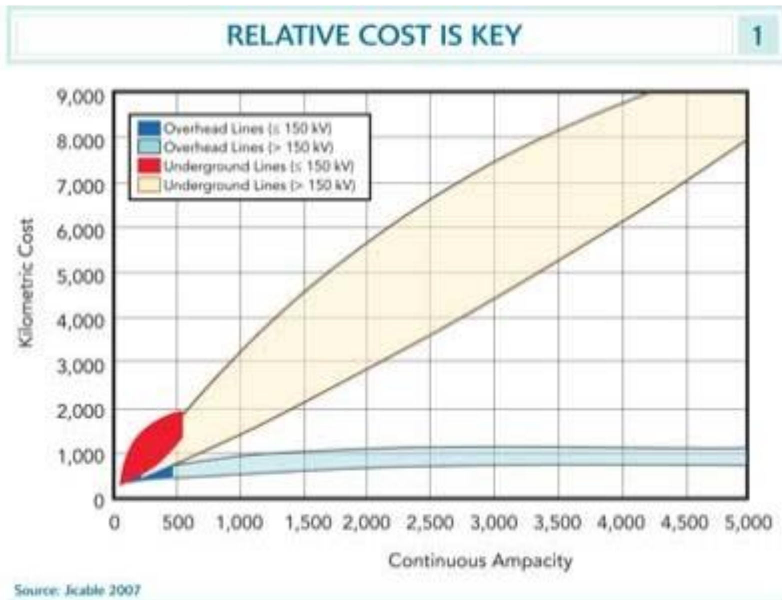

Figure 21: The Relative Costs of Different Lines (Tarimo, 2011)

Deciding on the right technology to use is a fundamental step to building a new line. However, because of the variety of report comparing overhead and underground systems without a standard to be used by the different stakeholders involved in building new line the process to build new lines is complex.

2.5 Planning Approval Procedure

Efforts to upgrade the grid in Switzerland and many parts of Europe often run into opposition by members of the public and environmental groups who are opposed to the upgrade in one way or another. Since Switzerland has a direct democracy, it may be even more difficult to get projects off the ground than in other European countries. Even a single individual purportedly affected by the upgrade can block the project for an extended period of time until the Swiss Cantonal Court and the Swiss Supreme court decide between the two parties. Often the approval process takes years, and sometimes the upgrades are abandoned or changed completely because the technology has changed by the time the line is approved (Swissgrid, 2014).

The approval process to build new lines has two stages, the Sectoral Planning stage and the Planning Approval procedure. The Sectoral Plan is the proposal for the building of new lines where the type of line and locations are specified, while the Planning Approval procedure is the specific plan for building a particular line. Figure 22 shows the sequence of operations for the approval process for new lines (Swissgrid, 2014).

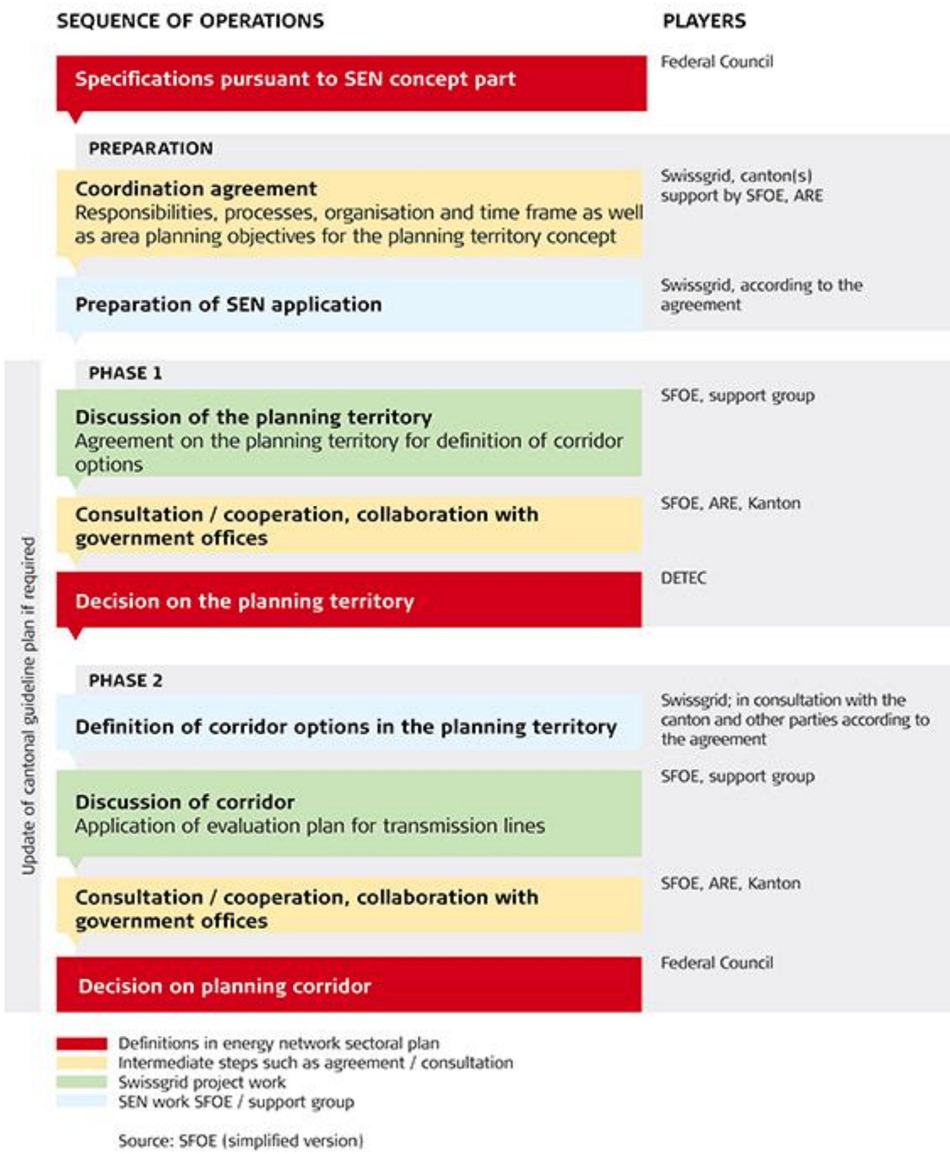

Figure 22: The sequence of operations for the development process for new lines (Swissgrid, 2014).

The Sectoral Plan consists of two main phases but before the plan can be launched the transmission operator and the canton or cantons involved conclude a coordination agreement which guarantees that the interests of the cantons are incorporated in the early stages of the planning process. The transmission operator must then submit the application for inclusion in the sectoral energy network (SEN) plan which allows proposals to be put forward for the grid lines (Swissgrid, 2014).

During Phase 1, the transmission operator proposes the different corridors on which the new line can be built, showing the advantages and disadvantages of each. The type of line is also taken into consideration. During this phase the transmission operator evaluates if cabling of the transmission lines is possible or if a system of partial undergrounding can be used. After the submission, Swiss Federal Office of Energy (SFOE) makes recommendations on the proposals filed in the SEN application (BFE, 2014).

During Phase 2, a support group may recommend a preferred corridor for the line. The support group consists of stakeholders that have an interest in the line which consists of the interested Swiss federal offices (ARE, SFOE, BAV, etc.), the ESTI, the ElCom, the cantonal authority's involved, environmental groups and the transmission operator (Swissgrid, 2014).After the support group chooses a corridor the office of energy decides on the final corridor based on the group's recommendation (BFE, 2014).

The planning approval process is initiated after the final corridor is chosen by submitting an application for planning approval. After the transmission operator finalizes the details specified in the Sectoral stage, projects are closely examined, to verify that they meet the safety requirements and legal provisions. They also examine construction projects to ensure that they are reconcilable with the interests of private individuals (property owners, local population) (Swissgrid, 2014).

The Swiss Federal Inspectorate for Heavy Current Installations examines the application and either grants planning approval or asks for certain changes to the project. Individuals are allowed to voice their opposition for the new lines and if the inspectorate cannot reach a compromise with all objectors and settle disputes between the involved federal authorities it sends the documentation to the Swiss Federal Office of Energy. The Office of Energy negotiates with the parties concerns and issues a planning approval ruling (Swissgrid, 2014).

Appeals may be filed to the Swiss Federal Administrative Court, and finally to the Swiss Federal Supreme Court as a last resort. In the best of cases the approval process can take nine to twelve years, but where there is substantial opposition and disagreement among the various stakeholders the process may take as much as 30 years (Swissgrid, 2014).

In the last few years there were a few instances where the line was approved and others the lines were cancelled like the Yverdin-Galmiz line mentioned previously. The planning for the Chammoson-Chippis line in the canton of Valais started in 1992 as Figure 23 shows. The project was to build 2 x 380kV lines and one 220kV line.The sectoral planning for the project didn’t start until ten years later in 2002 and it wasn’t until 2009 that the office of energy officially approved the new line (Swissgrid, 2014).

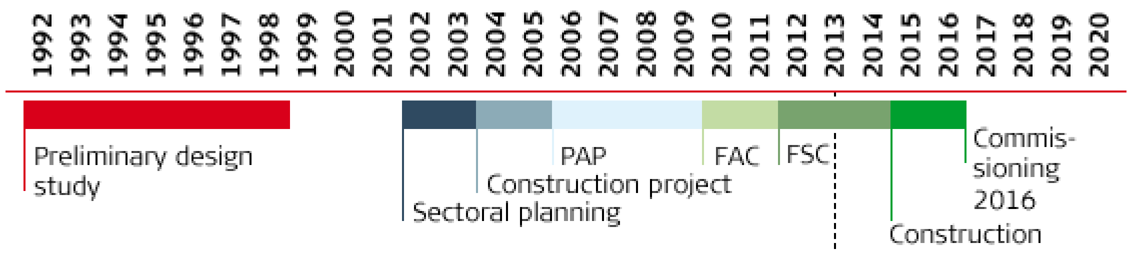

Figure 23: Timeline of Chamoson-Chippis Transmission Line (Swissgrid, 2014)

After the Office of Energy approved the line, several individuals affected by the line were still unhappy and decided to oppose it in court. The individuals complained to the Swiss Federal Administrative Court; they called for a full or partial undergrounding of the 380kV line, minimizing energy losses and the reduction of noise pollution. Noise pollution is caused from above-ground high voltage lines or from the transformers of a high voltage substation (Elia.be, 2013). After a year of considering the situation, the SFAC accepted minimizing the energy losses and the reduction of noise pollution, but decided against undergrounding the line in August 2012. The individuals appealed the decision to have an overhead line in the Swiss Federal Supreme Court. The Supreme Court ruled against the individuals, rejecting their complaints a year later on July of 2013. The entire process for the proposal, review, and approval of the Chammoson-

Chippis line will have lasted 24 years by the time the line is operating, which is average for building new lines in Switzerland (Swissgrid, 2014).

Another project that was recently concluded involved the Linthal 2015 power plant project between Beznau and Mettlen for the Riniken/Umiken subsection. Swissgrid proposed to build two 380-kV connection lines to the Linth-Limmern pumped storage plant. The preliminary study phase took about a year, as shown in Figure 24. The sectoral process was also much quicker, although locally affected individuals appealed the Office of Energies decision to grant permission to the line. The affected citizens wanted the line to be undergrounded instead of overhead. The Swiss Federal Administrative court ruled that the lines need to be buried, after reviewing the technical reports on cost, benefits, and feasibility of an underground cable. In the end, the court sided with the local citizens in choosing to preserve the aesthetics of landscape (Axpo annual report 2006/2007).

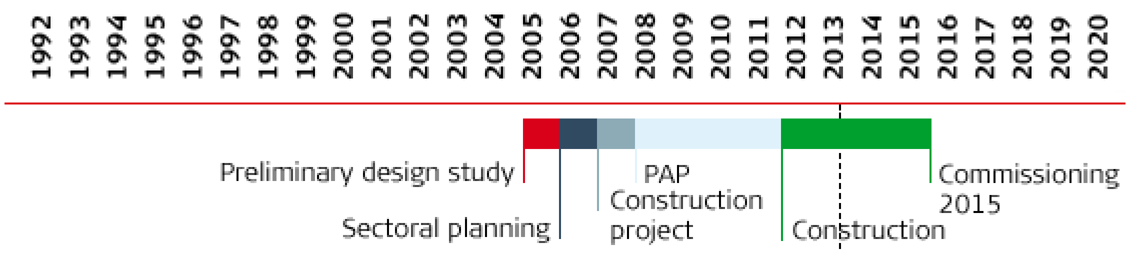

Figure 24: Timeline of Linth-Limmern transmission line. (Swissgrid, 2014).

Axpo was required to use cables instead of overhead lines for the project. Nexans, the cable manufacturing company was chosen to supply six 380 kV XLPE-insulated underground cables, approximately 5km in length, compared with the original lines needed for an overhead system (Nexans press release, February 2010).

2.6 Conclusions

The Swiss electrical grid needs to be updated to accommodate the future requirements of European countries. The discussion started with the debate of the need to expand the electric grid, and continued with how to effectively expand the existing transmission system while appeasing the concerns of all parties affected, including environmental groups and utility companies. One of the prominent debates was between installing overhead lines, or underground cables. The latter option would avoid the aesthetic damage caused by large overhead power lines crossing the landscape, while the overhead lines are undisputedly the less expensive option. The costs must be weighed against the visual and environmental damage.

The process of installing new lines was another concern that was brought to light. It takes a very long time from the beginning preliminary study to the completion of a line – generally between ten and twenty-five years. All in all, this multi-faceted issue must be continually addressed and reworked in order to keep all parties satisfied.

3 Methods

3.1 Goal

The primary goal of this project was to analyze the need for upgrades in the electrical grid, compare different technologies that can be used, and assess the regulatory process for approving new lines in Switzerland. Using data collected throughout the project period, we proposed methods to ensure the future electrical grid is reliable and meets everyone's needs.

3.2 Process

To achieve this goal, we built on our review of the literature by conducting an extensive set of in-depth interviews with different experts and stakeholders in the US, Switzerland and elsewhere in Europe, guided by our breakdown shown in Figure 25.

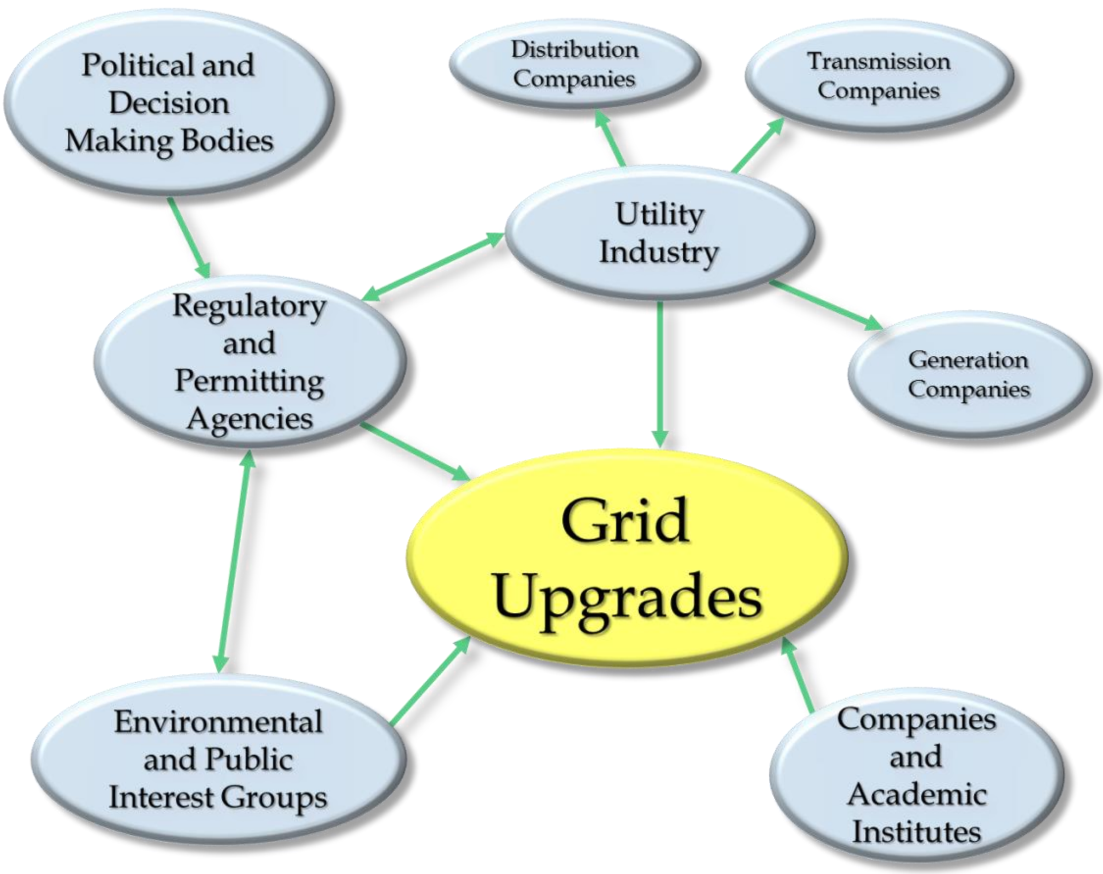

Figure 25: Stakeholders in the decision making process

Based on the literature we chose to divide the interviewees into four main categories:

1. The utility industry (including Swissgrid, power generators, and distribution companies);
2. Environmental groups;
3. Companies and Academic Institutes; and
4. Regulatory and permitting agencies at the federal and cantonal level, and other pertinent political and decision making bodies.

This project was conducted between March 17th, 2014 and May 2nd 2014. During that time our research in Switzerland entailed interviews with experts from the four key areas listed above. The results were then analyzed, and we developed a set of recommendations based on our findings. Figure 26 below shows the project schedule.

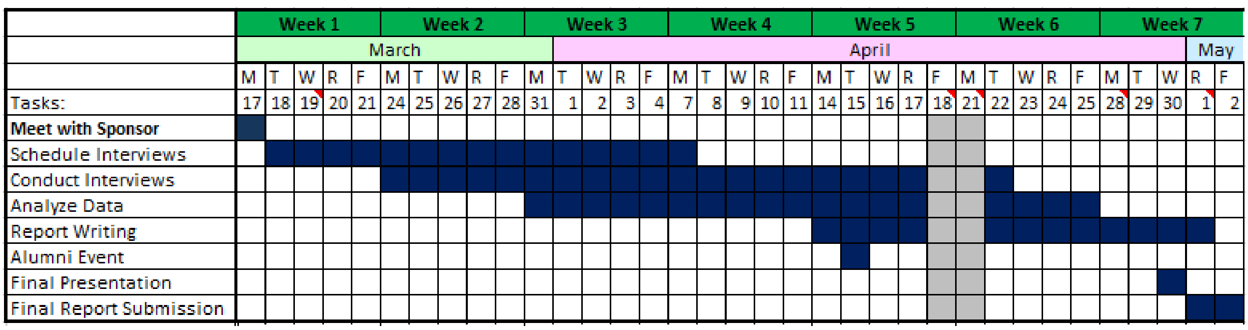

Figure 26: Project Timeline

We chose to use in-depth, semi-structured interviews rather than standardized questionnaires or surveys because we had a relatively small number of key informants, and we felt the interview format would better allow us to tease out the nuance of the arguments made by the interviewee. The general methodology we used for interviews consisted of three phases: Identify possible interviewees, develop interview questions, and conduct the interviews. We ended up interviewing 19 out of the 23 people we contacted, as shown in Table 6.

Name	Title	Organization	Type of Interview	Date of Interview
Thomas Oswald	Lawyer	Office of Energy (BFE)	In person	4/23/2014
Martin Michel	Federal Office of Energy Networks Division	Office of Energy (BFE)	In person	4/23/2014
Jacques Bonvin	Co-Founder of Solstis	Solstis	Conference call	4/23/2014

Mr. Philippe Meuli	Head of Engineering / Projects at Swissgrid	Swissgrid	In person	4/16/2014
Stefan Schedl	Director of GIL Projects	Siemens	Conference call	4/15/2014
Jean-Francois Steiert	Delegate to inter cantonal affairs in the canton of Vaud	Swiss government and HTST	In person	4/14/2014
Florian Kienzle	Smart Grid Specialist	EWZ	In person	4/14/2014
Herbert Kanzig	President WWF Fribourg	World Wide Fund (WWF)	In person	4/11/2014
Francois Cochet	Engineering department manager	Nexans	In person	4/10/2014
John Orr	Professor in Electrical and Computer Engineering Department	Worcester Polytechnic Institute	E-Mail	4/10/2014
Keith Gray	Service Area Director	Center Point Energy	Conference call	4/7/2014
Fred Looft	Professor in Electrical and Computer Engineering Department	Worcester Polytechnic Institute	Conference Call	4/4/2014
Raphael Compagnon	Professor	Fribourg School	In person	4/1/2014
Dr. Tomasz Magier	System Product Lifecycle Manager HV Gas Insulated Lines	Siemens	Conference call	4/1/2014
David Rielly	National Energy Manager- Novartis Pharmaceuticals	Novartis	Conference call	3/28/2014
David Gautschi	Manager Technical Services/Head of accredited Test Laboratory	Alstom	In person	3/25/2014
Lasse Wallquist	Project Leader	Swiss Risk Dialog	In person	3/24/2014
Olga Galland	Researcher	Fribourg School	In person	3/17/2014
Rob Krueger	Professor in Electrical and Computer Engineering Department	Worcester Polytechnic Institute	In Person	2/28/2014

Table 6: List of Interviewees

3.2.1 Identify Possible Interviewees

We identified possible interviewees based on our review of the literature, including websites, government reports, and academic journals. We also consulted our sponsor and his colleagues at the Fribourg School of Engineering. Interviewees were chosen based on the stakeholder groups they represent and their professional knowledge and experience of the topics to be discussed. We then used a snowball sampling technique in which we asked each interviewee to suggest other key informants that we should interview.

3.2.2 Developing interview questions

We developed the interview questions based on our background research and in consultation with our sponsor and academic advisors. The questions are a mix of closed and open-ended responses, with an emphasis on the latter given the nature of the subject matter and the types of information we wish to acquire. We anticipated that we will have different sets of questions, one for each of the groups (see Appendices A-G, beginning on page 67) although we skipped some questions and emphasized others based on the knowledge and expertise of the interviewee as well as the stakeholder group they represent (see discussion below). We expected that our questions could evolve during the course of the interviewing as we discovered issues and topics that we had not anticipated. When it was necessary, we followed up with our initial interviewees to address any missing items.

3.2.3 Conducting the interviews

We conducted background research on each potential interviewee, looking at not only their present role in their respective organizations, but also their previous work history before contact. We e-mailed them to request an interview and to schedule a time and location that is convenient for them. We followed up with another email to confirm the interview and we sent key questions that we would ask during the interview.

Depending on the interviewee, we either interviewed in person, by phone, or via a video conference call. We preferred to conduct the interviews in person but this was not always possible given location and logistics or the preference of the particular interviewee, so phone interviews were required. Mere email exchanges were a poor substitute for in-person interviews since much of the nuance of the discussion was lost and it was difficult to note subtle cues, such as body language. At the end, most of our interviews were conducted in person.

Interviews were recorded with the interviewees' permission. Before each interview, we asked if the interviewee is comfortable with being recorded and if we can quote him or her. If not, we only took notes during the interview process. During the interview, one of our group members was the interviewer and the others took notes summarizing the conversation. We sent the interviewees a copy of their sections to review before submitting our final report.

In the following sections, we describe each of the four main groups individually and discuss how the interview content and protocols may be modified to accommodate the different types of stakeholders we interviewed.

3.2.4 Generators and Distributors in Utility Companies

It is very important that we interviewed representatives from companies and organizations from all the groups that we have previously identified in Figure 25. We interviewed those involved directly with the Swiss energy industry. This included the transmission system operator Swissgrid, power generators such as Axpo, Elecktrizitatswerk der Stadt Zurich (EWZ), and leaders within the Office of Energy. For the full list of our interviewees see Table 6.

We also interviewed experts from companies like Siemens or Alstom who are directly involved with GIL and other leading technologies to upgrade the transmission system. We interviewed Nexans as well, one of the main cable manufacturing companies in Switzerland, to see what plans they have for their technology.

3.2.5 Research institutes and academic experts

As our project evolved, we identified several professors at WPI that have experience with transmission lines in the Electrical and Computer Engineering department. We conducted these interviews via phone and video conference calls from Switzerland. We also reached out to other experts in the US, such as Center Point Energy and National Grid. Through our literature we also identified experts in Swiss universities working on transmission line projects or looking at the decision making process and we interviewed professors in the Fribourg School of Engineering.

3.2.6 Environmental and public interest groups

We conducted interviews with individuals within environmental groups to get a better understanding of the opposition to both new transmission lines and to see if GILs are something they would consider. There are currently a few groups opposing new transmission lines, such as Grune Les Verts, HTST, World Wide Fund (WWF) and the Green Party. We were able to interview representatives from HTST and the Fribourg branch of WWF. Most of these groups operate locally, and only a few of them have websites explaining more about their stance. It was of utmost importance that we try to interview individuals from these groups in person since it was extremely difficult to get more information about them online. It was also important to understand how the general public feels about the new technologies and new transmission lines.

3.2.7 Regulatory and permitting federal and cantonal agencies, and pertinent political and decision making bodies

To better understand how a project can be stopped by an unhappy citizen, we looked into the regulation and permitting agencies in both the federal and cantonal levels. Our interviews focused on the legal and procedural aspects of installing new lines and the ways in which the public and environmental groups can or cannot intervene in the process. We were interested in any possible upcoming changes to the decision process, so we interviewed leaders in the Office of Energy. We determined the policies that are imminent to the expansion of the grid on the federal and cantonal levels.

3.2.8 GIL and Cable manufacturing companies

To better understand the technical aspects of the different technology options, we talked to several cable and GIL manufacturing companies. Our interviews focused on the benefits and downfalls of the technology, and the projects working on advancing these technologies. We interviewed representatives from Siemens, Alstom, and Nexans to help round out our research.

3.2.9 Data Analyses

After completing the interviews, we analyzed the information received from the different groups and compared them to one another. The data from both the literature and the interviews helped us come up with a recommendation for the future of transmission systems in Switzerland. The analysis of the interviews from the various groups provided us with the key criteria for the development of a recommendation that takes everyone's opinions into consideration. We then analyzed the data gathered from the regulatory and permitting agencies to find the best way to implement the new technologies without opposing the views of any environmental groups or the views of the public.

3.3 Conclusion

By interviewing experts and stakeholders from many different groups, we were able to see the debate from several different sides. The transmission system in Switzerland and different technologies and strategies used to upgrade the system were reviewed and analyzed, and the following sections of this report present this data.

4 Findings

Before we started our interviews our background research suggested that the debate for overhead versus underground was the main debate for the electric grid in Switzerland. After conducting our first few interviews, however, we realized there was a much larger debate going on about the future of the grid. Different questions, such as which power sources should Switzerland use in the future, does the grid need upgrading and which technologies to use for the expansions came up. Taking this new information into consideration, we decided to refocus our project and break it down into three sections; the future of the grid, overhead versus underground, and the process for building new lines.

4.1.1 The Future of the Grid

The future of the grid in Switzerland is uncertain at the moment, with multiple debates and proposed changes aimed at making the grid more efficient and speeding up the decision making process. From our interviews and background research, we discovered that the stakeholders agree that the grid will continue to need upgrades and maintenance because of the aging infrastructure. We have discovered, however, that grid upgrades are not the main debate for the future of the grid, but the expansion of the grid and the amount of expansion needed in the future is much more contested.

Many lines are operating at the edge of their capacity and are in need of repair, and without continued maintenance the grid will not be able to sustain Switzerland's electrical demand. Since Switzerland is in the center of Europe, a large amount of energy moves through the Swiss transmission grid to provide power to neighboring countries. Phillip Muelli, Head of Engineering / Projects at Swissgrid, believes the grid will need to adapt to new demands for the integration of power being generated by solar, wind, and other renewables in France and Germany, as well as domestically (personal communication, 16 April, 2014).

Mr. Jean-Francois Steiert, a Delegate to Inter Cantonal Affairs in the canton of Vaud for the Swiss government and a member of the environmental group HTST, believes that Switzerland needs grid upgrades and ways to produce more energy. He said the Swiss would need to invest in using less energy and upgrade in the fine parts of the grid.

The environmental groups we spoke to on the other hand believe that there are other options. Instead of expanding the grid, Mr. Herbert Kaenzig, President of WWF Fribourg, believes Switzerland needs to move into a decentralized system. Raising energy prices could encourage people to use less energy, helping them achieve self-sustainability. He believes maintaining the current grid is possible, with only minor upgrades to accommodate new distributed energy sources and replace ageing lines and equipment. Kaenzig avers that transmission systems are used to transfer high voltage power over long distances, and by switching to a decentralized system new lines will not be needed to transport power over long distances. Additionally, Kaenzig asserts that by using more PV there will be no need to expand the grid to meet growing demand. He believes PV is an attractive option for Switzerland since there are many industrial roofs that can be used for solar arrays. Also, at higher elevations there is less winter fog that is typical in the valleys of Switzerland, so even in the winter months the solar harvest can be large. Kaenzig believes that Switzerland can use their hydro power plants to generate the extra power needed at night and at times when the solar production is low (personal communication, 11 April, 2014).

With the Energy Strategy 2050 plan underway to connect the European transmission systems, Swissgrid is under increasing pressure to expand their grid and increase the grid's security. The amount of power running through Switzerland to other countries is approximately as much as the power used in Switzerland itself. Cross country power trade is very important to Switzerland and many surrounding countries. Kaenzig believes, however, that the grid would not need to grow since the amount of energy being transferred through Switzerland will not increase by a large amount.

Meuli believes that decentralization of electricity is a promising method to approach the future of the grid. With increased investments in offshore wind farms and the generation of energy at large production sites, however, transmission systems will remain a critical part of transporting the electricity over long distances (personal communication, 16 April, 2014).

Moving towards a decentralized system is something utility companies in Switzerland are exploring. Mr. Florian Kienzle, a Smart Grid Specialist with the power company EWZ, believes Zurich cannot be fully self-sufficient on PV alone; but it could use PV to provide a significant portion of the electricity needed. He estimates that even under the best possible conditions, it is only feasible to produce 1TWH from solar out of the 3TWH needed for all of Zurich's current electricity needs because the density of buildings is too high and there is not enough roof space suitable for PV installations (personal communication, 14 April, 2014).

Over the last few years, German PV usage has boomed because of the increased government subsidies. "It's a train that's begun to roll and cannot be stopped anymore," according to Kienzle. In Germany there are many incentives to use PV, and the prices are highly subsidized, which has encouraged extensive adoption by residential and business customers. Switzerland also offers some incentives, but the government will only pay up to 25%-30% toward the purchase and installation costs of residential and industrial PV systems. The same incentives are offered for utility companies building hydro power plants or wind farms. The subsidies in Switzerland are capped to limit government spending, and as a result the PV boom has not yet hit Switzerland. Kaenzig and other environmentalist think the government should promote PV more vigorously. Although, Kienzle believes the PV boom will come anyway because "if the decentralization continues, the pricing of PV will become more competitive and easier to implement" (personal communication, 11 April, 2014).

According to Mr. Martin Michel, from the Federal Office of Energy Networks Division, and Mr. Thomas Oswald, a lawyer working for the federal Office of Energy, one of the differences between the German and Swiss Energy policy regarding solar power is that the energy policy is influenced primarily by politicians in Germany and changes can be made much more quickly (personal communication, 23 April, 2014). In Switzerland, however, the people have a very direct say in how a project will play out and have the ability to raise objections repeatedly, each time adding years to the decision making process.

Whether or not the grid needs upgrading and expanding is not the only debate going on. There is also a debate about where to lay the new lines and which technologies to use.

4.1.2 Swissgrid on the 2020 and 2050 expansion plans.

Kaenzig believes that Swissgrid's grid expansion plans need to be extensively reworked because of the phasing out of nuclear energy under the 2050 Strategy. In the next few months, the citizens of Bern will vote on whether or not to shut down Muhlenberg, the oldest nuclear power plant in Switzerland, before its operational life ends. There are as yet no shutdown dates for the four other operating nuclear plants. Swissgrid's expansion plans assume the continued operation of these nuclear plants, but by the time these upgraded lines and other expansion projects are approved by everyone involved, the nuclear power plants might be decommissioned entirely. Swissgrid is currently working on an updated plan for the future incorporating these and other changes in the power generation in Switzerland.

Michel and Oswald believe that along with more renewable energy, Switzerland might use more natural gas to generate electricity in the future. Since the environmental groups are pushing for decentralized power and many groups are against using nonrenewable resources for power generation, including natural gas, this is certainly a process which will take years to put into action – if it happens at all (personal communication, 23 April, 2014).

The Office of Energy is currently working on changes to the energy policy, to not only incorporate the changes in energy generation but also to give the general public more information about the upgrades and the different technologies that can be used. The Office of Energy is trying to make the energy planning and decision making process in Switzerland more transparent since the technologies are very complicated, and at the moment individuals oppose projects without knowing the facts behind the projects. The delays can cost hundreds of thousands of dollars, and in the future the delays might compromise the security of the grid (Meuli, personal communication, 16, April 2014). After the blackout in Italy and Switzerland in 2003, the transmission operators in Europe have been very cautious about grid security and for that they need the best technology for any grid expansions and upgrades. This often leads to a discussion of the tradeoffs between underground and overhead cable options.

4.2 Underground vs. Overhead

The debate about which technology to use for grid expansion has been going on for years, and it is unlikely to end any time soon. All of the experts we interviewed are in agreement that underground cables are the best option for the low voltage lines at the local distribution level. Our interviews corroborated what we found from our background research, and this was the main reason we chose to focus on the transmission level instead of the distribution level.

According to the plan regarding the distribution grid developed by the Office of Energy, utility companies will be required to use underground cables if the price difference (when compared to an overhead equivalent) is below a 2.5:1 or 3:1 ratio. Since the process is much more complicated for the transmission level, the Office of Energy is not planning to use a simple cost factor to determine whether or not transmission operators have to use overhead or underground cables for very high voltage systems. This effect may help speed up the discussion for the transmission level since there will be less opposition for the distribution level.

The main two options for electric transmission systems in Switzerland are overhead lines (OHL) and underground cables (UGC). Although we initially identified Gas Insulated Lines as another possible option, after conducting our interviews we found that GILs are not yet really a part of the debate in Switzerland, although some parties, such as Siemens that manufactures them, have been pushing for their incorporation especially elsewhere in Europe. There are two main reasons for excluding GILs in the debate; the first is the cost. GILs still cost significantly more than any of the other options and require much larger upfront investment. The second reason is that until now, GILs have not been used for long distances, and their use is only really practical when the power being transmitted is very high. Dr. Tomasz Magier, System Product Lifecycle Manager HV Gas Insulated Lines for Siemens, said they are currently working on ways to make GILs more affordable and rewarding when used for longer distances (personal communication, 1, April 2014). Magier said there are various benefits to using GILs over cables despite the high cost. One GIL can support as much current as 6 or 9 cables, and also boasts the lowest energy losses of all the different technologies. Despite being a possible option for transmission systems, we believe GILs are not yet a very attractive option for the stakeholders in Switzerland. If Siemens and other GIL manufacturing companies are right and GILs become more affordable in the future, they may prove to be a very good option because of their high efficiency and reliability. Steiert said that the environmental groups in Switzerland are accepting of any underground option and if GIL advances in the next few years they may push for it in the future (personal communication, 14, April 2014).

Steiert, and Kaenzig both believe that an underground system, whenever possible, is the best option for the environment and affected citizens. The environmental groups would prefer an underground system to preserve the landscape and limit public exposure to EMF. Meuli also mentioned that individuals oppose the installation of large overhead lines because of the decrease in land values nearby. Land is very valuable in Switzerland, and although the land directly under a power line must be purchased by Swissgrid, the surrounding landscape also loses value.

Meuli asserts that having only an underground system at the 220 kV or 380 kV levels is difficult and quite complicated. This was affirmed by Martin Michel and Mr. Francois Cochet; Engineering department manager from Nexans (personal communication, 10, April 2014); both saying that an entire underground system will be very difficult to implement. Michel thinks the main issues with an underground system for transmission lines are the unsolved technical problems, such as resonance. An entirely long distance underground high voltage system has never been implemented before, and no one is really sure about how such system will affect the rest of the grid electrically. Cochet and Meuli, on the other hand, believe the main obstacle is the cost and the complications that arise with long distance cables. One of the complications is the transportation of the cables themselves. At 380 kV, a meter of underground cable can weigh around 45 kg. Transporting a few kilometers of cable can end up weighing over a hundred tons and it is extremely difficult and costly to transport across the countryside. Also because of the capacitance and the physical transportation limitations, each section of cable must be relatively short. This means that every 500 meters to 1 km a linkage is required to connect the next cable section. Each linkage adds more risk of failure, and increases the cost. When compared to an OHL, this difference is substantial as an overhead line can be more than two kilometers in length before a linkage is needed.

When comparing OHL with a UGC of the same specifications, Swissgrid compares physical units/parameters, economic conditions, landscape protection, flora and fauna disturbance, global footprint, operation restrictions, investment and reinvestment cost, and many more. This is all a process designed to make the correct choice regarding the installation of an OHL system or an UGC.

Switzerland has very strict EMF limits of 0.1 micro tesla. Overhead lines can fall within this limit, but Cochet averred that with cables EMF can be completely avoided. “It’s a question of shielding which costs money, but it’s possible to negate the EMF effect,” Cochet said (personal communication, 10, April 2014). He mentioned that you can add screen layers on top of the cable trough as well as directly in the cable insulation, which can completely negate EMF. Additionally, if the three cables carrying the three phases are placed very close to each other, the EMF cancels itself out very quickly and can often not be detected at all at a distance of only one meter away. Then you can add a screen around the three cables together, and the EMF will be completely avoided – but at additional cost.

The cost of underground lines is considerably higher than that of overhead lines. Cochet said that having an entirely overhead system is by far the best option from the perspective of the utility companies. The cost is much less, it is a proven technology that is extensively used and very well understood, and it is not a very complicated system to use. He believes that having an entirely underground system is impractical because of the hefty cost difference. Despite the complications, underground cables are still an option Swissgrid considers for all of the new planned lines. Mueli said "We are not against cables, we just have to be honest and say where does cable make sense, and where does overhead make sense?" (personal communication, 16, April 2014). Michel reminded us, however, that preserving the aesthetics of the landscape is very important to the people of Switzerland. Switzerland is a very small country and often there is no room to install the overhead lines without detracting from the aesthetics of the landscape and the companies are required to place them underground.

Steiert believes the reason the utility companies aren't fully accepting of underground systems is because the utility companies are conservative in Switzerland and feel more comfortable using the old technologies, which has been effective for many years. "Not wanting to change the technology is human nature," he said, "If we need to progress in this new technology we need to take risk," (personal communication, 14, April 2014).

Cochet believes the best option is to use a partially underground system, using underground cables in sensitive areas and overhead lines for the rest of the system. This will decrease the cost but increase the complexity of the system.

This problem is not exclusive to Switzerland. Many countries around the world are experiencing similar debates. In the USA, utility companies are wondering whether or not they should start using underground systems. Mr. Keith Grey, Service Area Director for Center Point Energy in Texas, USA, believes Center Point Energy will only be using underground in the distribution level in the next few years (personal communication, 7, April 2014). For the transmission level, however, he said they have to think very carefully about which technology to use. Even though underground is less prone to weather damage, in some areas of Texas that have a high chance of being hit by a hurricane, OHL might be the better option because the storms often flood the underground systems and wash them away.

From our interviews and background research we realized that it’s extremely difficult to compare overhead and underground systems. Not only dos the price change with the different criteria compared, but the change is not linear in a lot of the cases.

4.3 The Process

Perhaps the largest problem is not deciding which is the best technology to use, but rather when to use each of the different technologies. The office of energy is currently working on a way to make the process more transparent and to set a standard for when to use each technology so there can be less opposition in the future. In 2013 the Office of Energy published Bewertungsschema, guidelines for evaluating transmission lines to compare the advantages and disadvantages of cable versus overhead options on a case-by-case basis. The guidelines require an evaluation of the technical, environmental, and economic aspects of each project, as well as considerations of the impacts on land use and planning. Figure 27 illustrates the necessary balance of these aspects, and shows how the weighting of each factor must be equal for the system to be successful.

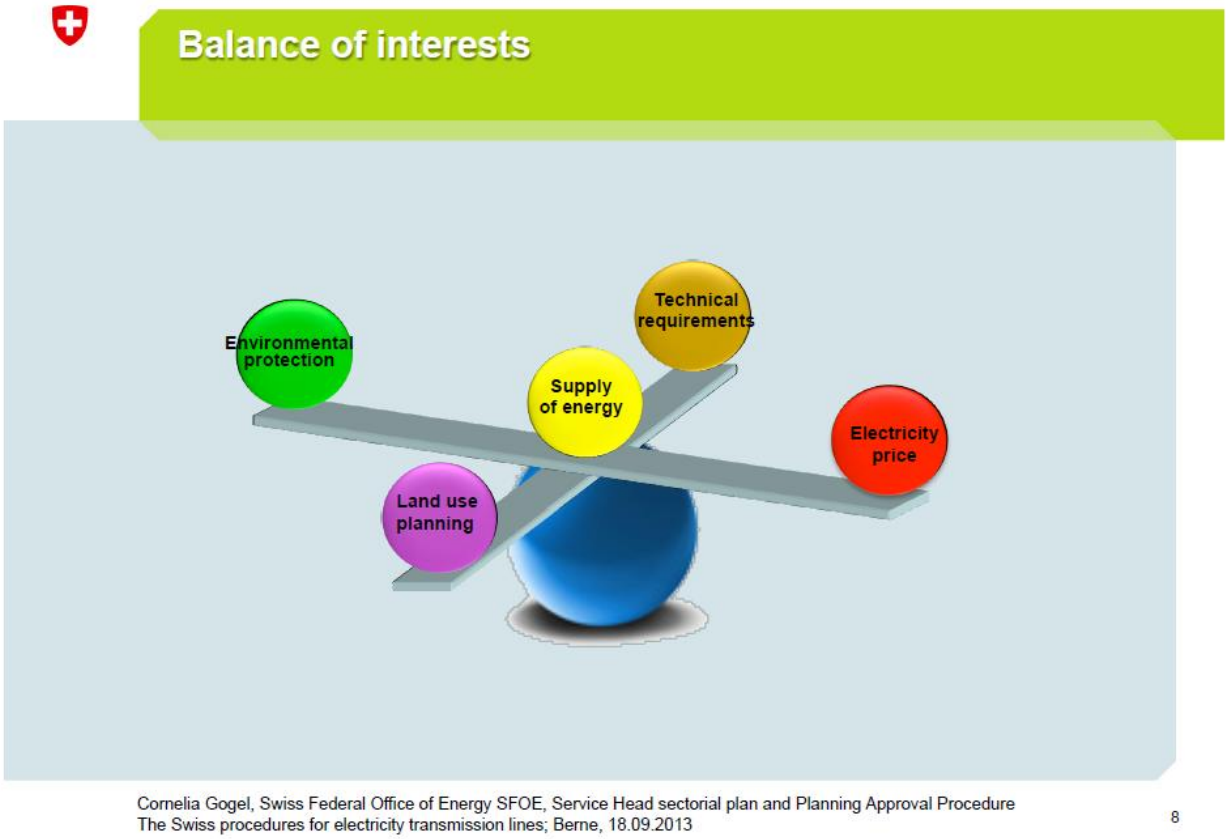

Figure 27: Balance of Interests (SFOE, 2013)

The main reason for much of the public opposition to new lines and grid upgrades is because environmental groups and locally affected individuals believe the investment in underground transmission systems is worth it. Kaenzig, of the WWF, said you cannot put a price on preserving the landscape, and despite overhead lines being much cheaper, the visual impact will last forever and will affect land value, tourism, and even the health of the residents living near the lines due to EMF radiation (personal communication, 11 April, 2014).

Another factor to consider is the time it takes to build a new line. Steiert, Delegate to inter-cantonal affairs in the canton of Vaud, mentioned that projects with a lot of opposition generally take 15-25 years to get off the ground, while projects with little or no opposition might take as little as six years from planning to implementation. A few years ago, in the Canton of Ticino built the first underground transmission line; a high voltage underground cable was built and the entire project took six years to complete. Steiert believes the money wasted during the extra years of wrangling over the approval of overhead lines could instead be invested in underground options. He believes that ultimately, the underground options might even be cheaper in retrospect.

Steiert pointed out that Swissgrid published a study that examined the investment and lifetime costs of overhead versus underground lines. The study concluded that there would be a 10% increase on the price of electricity with an underground system. Kaenzig and Steiert both believe that cost is not really the main issue, however, but rather the utility companies not wanting to change a system that is already proven to be working.

Meuli admits that it is not the technical issues stopping Swissgrid from using underground cables, but rather the procedural complications associated with maintaining and building an underground system. Meuli also said that Swissgrid needs to be fair in building cables. For instance, if a cable is installed in a comparable location where an overhead line was installed in previous years, the individuals around the overhead line may demand a cable instead because "the others got one" (Meuli, personal communication, 16, April 2014). Swissgrid has to try to treat everyone fairly.

One promising solution to the expense of having a fully underground system or the visual impact of an entirely overhead system is to use a mix of both. In areas of dense population, or where the land value or views are extremely important, a section of underground cable may be the preferred option. For long stretches, where the land values are lower and preserving the environmental aesthetics may be less important, lower cost overhead lines may make more sense. "One of the issues with [a mix of underground and overhead lines], is that you need to have to have the stations that connect underground and overhead, which take up space," Cochet said (personal communication, 10, April 2014). These stations are quite large and visually unappealing, but can sometimes be hidden from view by hills or forests to help mitigate the impact. A partially underground system is something the environmental groups and Swissgrid both mentioned might be possible; with the extra complications, however, it is far from an easy process.

Facts about the different technologies themselves are often one of the points of disagreement between the stakeholders. There are dozens, if not hundreds, of published reports comparing overhead and underground systems, but the findings and conclusions vary substantially between them based on differing assumptions. Having a standard evaluation and decision making process to determine the different option will help significantly, but because the technologies are changing with the times, the standard might become outdated quickly.

Over the last few years the public's perception of the technical problems has changed according to Dr. Lasse Wallquist, project leader for the Swiss Risk Dialogue Foundation (personal communication, 24, March, 2014). With the use of the internet, information about different technologies is available to anyone at the click of a button and decisions that were once made by the utility industry and companies alone are now being closely examined by everyone. This is the case all around the world, but perhaps more so in Switzerland because of its direct democracy system.

Swissgrid and other utility companies are taking notice of this and are trying to change their current system to make it more transparent for everyone affected. Wallquist emphasized that you need to build trust between the two parties, otherwise things will take much longer. In the absence of trust, opposition to the building of new lines would slow down projects for decades until the issues are resolved in some fashion or the plans withdrawn. Sometimes the technology or markets would have changed by the time the dispute was resolve, and Swissgrid might have to start the planning process from scratch (Meuli, personal communication, 16, April 2014).

As mentioned earlier in the report the decision making process for building new lines has two main part the sectoral process and planning process. During the sectorial planning process environmental groups can make a proposal to the authorities to alter the route or the technology type. They submit a four pillared comparison: technology, landscape protection, ecological aspect, and human protection. The report is presented to the public, and then the directly affected stakeholders can oppose the project if they choose.

The three stakeholder groups involved in the decision making process are (1), the communities directly affected by the proposed new lines, (2), the cantons in which the lines are located, and (3), the federal government. Each level has to be involved and there needs to be a specific plan for everyone. This plan has to be synchronized so that when the Office of Energy gets involved all the problems are worked out. This process generally takes a long time and is one of the reasons the sectoral process can take years.

After the line is approved, Swissgrid must then secure the corridor in which the lines will be built. Mr. Mueli says that two out of three people will sell their land to Swissgrid, although some may need to be 'incentivized' through additional payments. The last one third of property owners will fundamentally refuse and take the issue to court, which may delay the project for a year or two or even longer.

Currently, Swissgrid is investing a lot of time and money into improving communications between the different stakeholder groups from the beginning of the process so everyone is on the same page and understands the benefits and risks of the project from the beginning. Swissgrid arranges meetings for stakeholders and other interested parties to explain the proposals and show them 3D renderings of the project and its likely impact on the community.

Figure 28 shows the planning procedure for new lines for Swissgrid. The two main sections of the project are under the project tab number 3. The preliminary project, sometimes known as the sectorial planning phase and the approval procedure, is the planning phase described previously in Figure 22. During section 31/33 (the *preliminary project*), a corridor is chosen for the new line and the technology to be used is specified. After the project is approved by the Federal Inspectorate for Heavy Current and the Office of Energy, individuals are allowed to appeal their decisions in the cantonal court; and if needed, they can appeal to the Supreme Court. Appealing the court decisions usually delays the project several years at least. During that time, according Mr. Meuli, the technologies might change and if the court rules a few years later that the line should be undergrounded, then the project manager must secure the increased budget for the underground line.

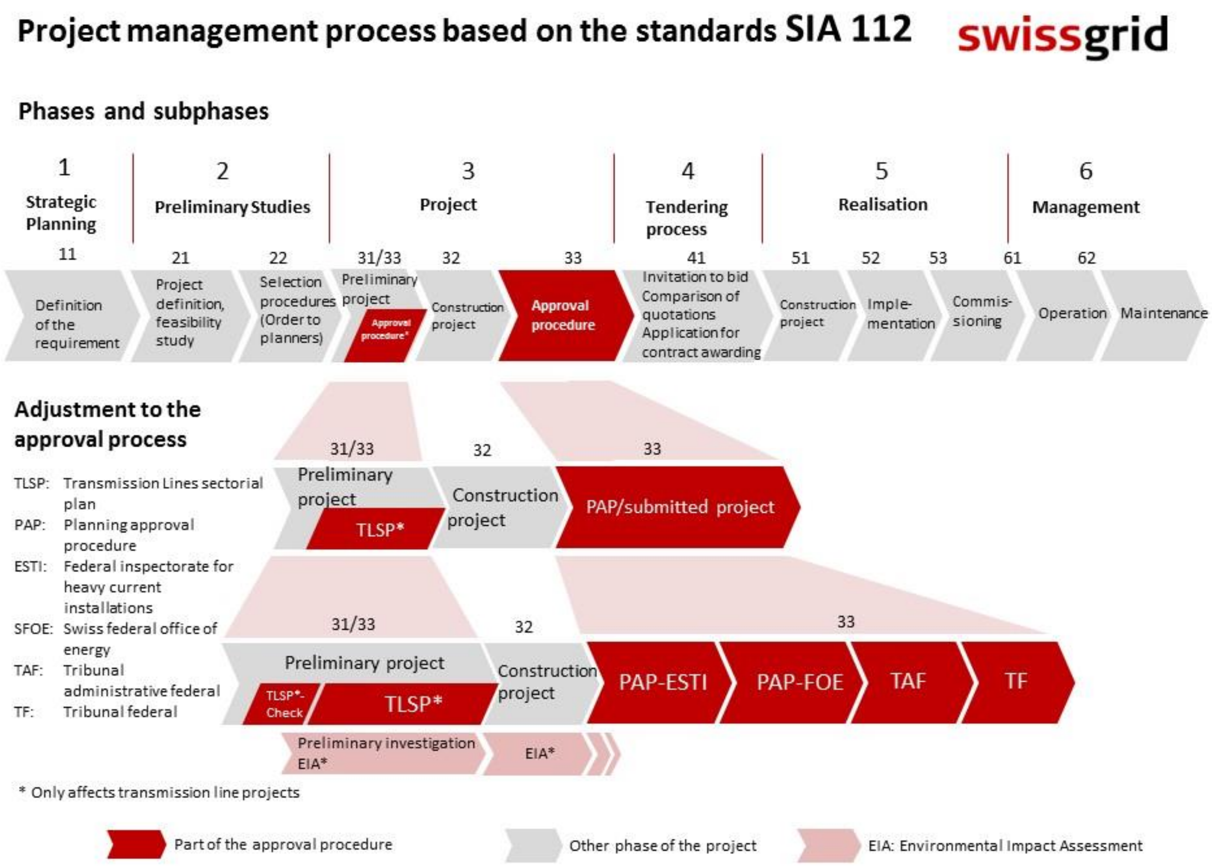

Figure 28: Swissgrids Project Mangement Process (Swissgrid, 2013)

For these reasons Swissgrid would like to change the process to not only speed it up but to also allow individuals to participate earlier on in the project. Figure 29 shows the proposed change in the decision making process to build new lines. The change occurs after the corridor and the technologies for the new line are chosen. Instead of waiting until after the Office of Energy approves the project, in this case individuals can oppose the line before the approval. This way the line type cannot be changed in the appeals to the courts years after it was originally approved by the Office of Energy. This process will also eliminate the possibility of appealing to the cantonal court and taking the case to the Supreme Court.

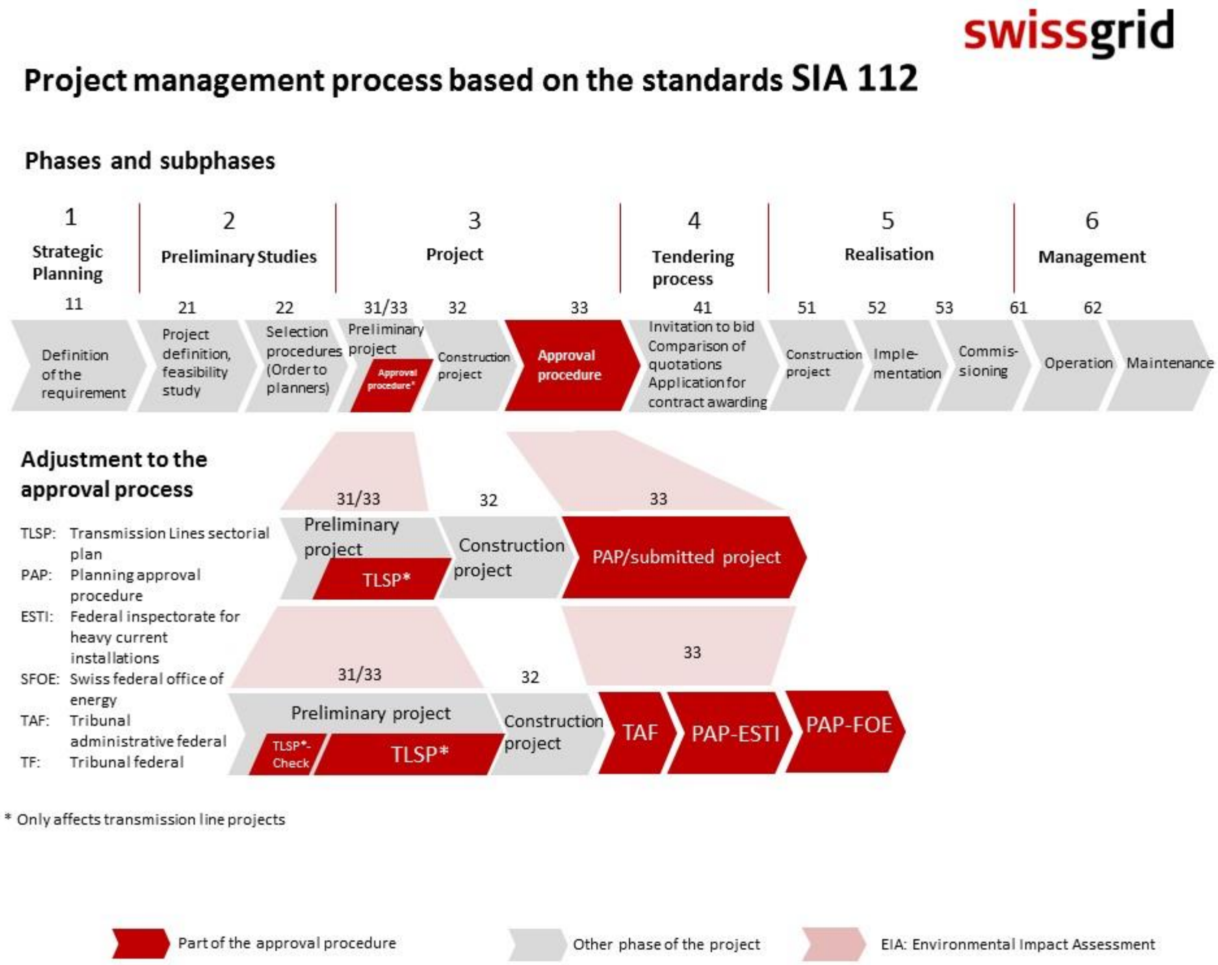

Figure 29: Changes to Swissgrid's Project Mangement Process

Swissgrid is currently working with the Office of Energy to see if this new process is possible. Under this new process, approval for new lines is expected to take six to nine years, instead of the typical fifteen.

Michel thinks that although the Swiss Federal Office of Energy is sympathetic to the changes proposed by Swissgrid and the need to speed up the approval process, the Office has several major concerns. Whenever a new line is being planned, the extended period of time allows everyone to have a say and, if necessary, the project can be changed. If the plans for a particular line change, the parties involved need to meet again and approve the new plans. If the decision making process is changed in the ways suggested by Swissgrid, the opportunities for changing the design plans are much more limited.

Mr. Steiert and Mr. Kaenzig both agree that changing the process along the lines proposed by Swissgrid will not be beneficial to affected members of the public. Currently individuals and environmental groups have enough time to appeal the lines and allow technologies to advance in the few years it takes the line to be approved. Mr. Steiert believes that if the process is shortened, rash decisions might be made about the future of the grid and more lines might be built because it takes less time to build them.

The Office of Energy is also working on changing the process for line approval. They want to make the process more transparent and encourage the involvement of all the stakeholders from an early stage. Over the last few years, Swissgrid has also invested money and time into including stakeholders early on in the planning process to minimize opposition in the later faces of the process. This investment has been working for Swissgrid over the last couple of years.

The main issue with the changes proposed by Swissgrid and the Office of Energy is the time factor involved with making them. Change in Switzerland takes a very long time to achieve. Mr. Michel believes the policy changes will be ready to be submitted to the parliament in 2016, which will then need a few years to review them before allowing the general public to vote on the changes. Meuli thinks that the changes will not happen until at least 2020, if not later.

5 Conclusions and Recommendations

The debates surrounding the future of the transmission grid in Switzerland are not easily solved. The different stakeholders agree that grid upgrades are needed, but they are in disagreement about the need to expand the grid, which technology to use for the grid expansions, the technologies to use to replace nuclear power, and how to make the build planning process more efficient.

5.1 The Future of the Grid

Conclusion 1: Swissgrid and the utility companies want major upgrades to the grid in order to replace aging infrastructure meet the growing demand for energy in Switzerland, and improve the reliability of the grid, especially given its role as the crossroads of electricity distribution in Europe.

Conclusion 2: Environmental groups are opposed to grid expansions to an extent. They believe that instead of investing in the growth of the grid, Switzerland should invest into moving into a decentralized power system. They are currently discussing the possibility of increasing incentives to switch to photovoltaic (PV) power with the Office of Energy. Environmental groups are also pushing for conservation of energy, by increasing electricity prices to decrease demand and the need for upgrades. They are willing to accept upgrades when they are essential for the operation of the grid.

Conclusion 3: Energy Strategy 2050 envisions the phase out of nuclear energy and the introduction of more renewable energy sources. The Office of Energy is currently working on changing the energy policy, including the inclusion of decentralized power sources.

Recommendation: Based on these conclusions, we recommend that the Office of Energy and other appropriate agencies work with Swissgrid, the utility industry, environmental groups and other interested and affected parties to work together to approve the changes in a time friendly manner.

5.2 Overhead vs Underground Conclusions and Recommendations

Conclusion 1: There is considerable debate about which technology to use for electric transmission systems. From our background research and interviews, we have concluded that there are considerable advantages and disadvantages of underground and overhead lines, depending on the assumptions made and the particular concerns of different stakeholder groups. We also concluded that gas insulated lines are not a part of the solution for Switzerland at this time.

Conclusion 2: The utility companies and Swissgrid prefer to use overhead lines because they are an established technology and more cost effective than underground lines. Environmental groups and individuals living close to transmission lines prefer underground systems, because they have less visual impact and are presumed to be safer for the residents. Using a partial underground system might be a good compromise between the two sides.

For these reasons, we make four recommendations:

Recommendation 1: We recommend Swissgrid look into using a partially underground system for all of their lines.

Recommendation 2: Since the main concern of using overhead lines is the aesthetic impact on the landscape, we recommend Swissgrid look into developing more visually appealing towers for the overhead lines**.**

Recommendation 3: The Office of Energy currently has criteria to help utility companies, Swissgrid and environmental groups decide on which is the best option for the new lines. However, the criteria are only used to develop an argument and the different stakeholders are not required to take them into consideration when making final decisions. We recommend the Office of Energy set a standard for using overhead and underground systems. We recommend revisiting the standards and technology options as technologies and specifications change.

Recommendation 4: The Netherlands capped the total length of overhead lines for both the transmission and distribution levels. Ever new overhead line must be compensated by changing the same length at a different location into underground cables. This approach has led to the speedy implementation of many transmission lines. We recommend for the Office of Energy to work with Swissgrid, and the other stakeholders to look into a similar policy and find a compromise that will please the different groups.

5.3 Public Process to Approve New Lines

Conclusion 1: The process for building new lines often takes between fifteen and twenty five years to complete. If the technology and other factors have changed during that period, the utility companies might need to start the project from scratch or make extensive changes to the project which causes further delays to the new line. Swissgrid is proposing procedural changes that will speed up the process. The new process allows individuals to oppose the new lines in the Cantonal Court before the Office of Energy approves the new line. After the decision of the court and the Office of Energy approves the line, no one will be able to oppose the new lines. The environmental groups are opposing the speeding up of the process, since the current system gives them enough time to oppose the new lines. They believe the current process allows Swissgrid time to really think about the lines they want to build. Another worthy point is that Swissgrid is currently trying to include environmental groups and stakeholders early on in the process to avoid opposition afterwards. This is favorable for Swissgrid, reducing the time to build lines by a few years at least. We recommend Swissgrid include stakeholders in both the Energy Strategy 2020 and 2050 plans, which would allow environmental groups to express their concerns years before some of the lines start their approving process.

Conclusion 2: The Office of Energy is proposing changes that will make the process quicker, easier, and more transparent for the stakeholders involved. It hopes to help speed up the approval process without limiting due process for opposition groups.

Recommendation: We recommend that Swissgrid and the Office of Energy work with the opposition groups to find a compromise to speed up the system without limiting the period of opposition.

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Appendix A

Electric Generation/Distribution Companies Interview Script

Preamble

Hello, we are students from Worcester Polytechnic Institute here working on a project. We would like to ask you some questions about electrical transmission lines in the power grid. We want to record the interview, if you are not comfortable with that please let us know, and we will only take notes. Again, we thank you for taking the time out of your day to speak with us.

Questions

- Can you tell us a little about your current role and responsibilities?
- How long have you been at your current job?

Technical

- As you know, we are curious to find out about potential upgrades to the grid in Switzerland, so perhaps we can jump right in by asking you if you would explain why you think the grid does or does not need major upgrades.
- As a shareholder in Swiss grid, how much of a say do you have on the grid expansion?
    - Will the cost of expansions affect you as a power generation/distribution company, if so how?
- Clearly there are many different technological options for upgrading the grid. What options do you think are most promising and why?
    - What are your thoughts on the debate between overhead and underground transmission systems?
    - What are the setbacks of using GIL or cables vs. Overhead? What are the benefits?
    - Do you see Swissgrid using more cables and GIL's in the future?

- Now that Nuclear power plants are being phased out what do you think is the best option to replace the 40% of power generated by them?

Political

- What is the federal government doing to promote grid upgrades and is there a consensus among the parties about how to proceed?
- What role do the cantons play in supporting or opposing grid upgrades?

Sign Off

Thank you again for taking your time to speak with us. We really appreciate it. We were wondering if we could contact you later if we have more questions. Who else should we talk with to get better insight?

Appendix B

Swissgrid Interview Script

Preamble

Hello, we are students from Worcester Polytechnic Institute here working on a project. We would like to ask you some questions about electrical transmission lines in the power grid. We want to record the interview, if you are not comfortable with that please let us know, and we will only take notes. Again, we thank you for taking the time out of your day to speak with us.

Questions

- Can you tell us a little about your current role and responsibilities?
- How long have you been at your current job?

Technical

- As you know, we are curious to find out about potential upgrades to the grid in Switzerland, so perhaps we can jump right in by asking you if you would explain why you think the grid does or does not need major upgrades?
    - What are some of the main projects Swissgrid is working on now to upgrade the grid?
    - What are some of the key barriers or obstacles that have to be overcome in order to upgrade the grid and how do you see these playing out in the future?
    - Can you tell us more about the procedure in Swissgrid for building new lines or upgrading current lines?
    - Who are some of the decision makers for expanding the grid?

- Clearly there are many different technological options for upgrading the grid. What options do you think are most promising and why?
    - How do you decide which option to use?

  - What are the setbacks of using GIL or cables vs. Overhead? What are the benefits?
  - What are the cons of using Overhead lines?
  - Do you see Swissgrid using more cables and GIL's in the future?

Social

- How has the debate about grid upgrades played out in the public arena?
  - What concerns have members of the public raised, if any?
  - Who are the major opposition groups?
  - What strategy is your company following to win public support?
- We've been hearing a lot about the Yverdon-Galmiz project, Can you tell us a little more about the project and where it stands now?
  - What outcome are you expecting?
- What are your thoughts on the Chamoson-Chippis outcome?

Political

- What is the federal government doing to promote grid upgrades and is there a consensus among the parties about how to proceed?
  - What role do the cantons play in supporting or opposing grid upgrades?
  - What are your legal rights for building new lines on someone's property?

Financial/economic

- We know one of the major concerns about using cables and GIL's are the costs, how much do you see prices rising with using different options?
  - How will the upgrades be financed?
- We know some of your shareholders are the distribution and electric companies in Switzerland, how much of a say do they have on the type of line built?
  - Will they help finance the projects?

Sign Off

Thank you again for taking your time to speak with us. We really appreciate it. We were wondering if we could contact you later if we have more questions. Who else should we talk with to get better insight?

Appendix C

Environmental Groups Interview Script

Preamble

Hello, we are students from Worcester Polytechnic Institute here working on a project. We would like to ask you some questions about electrical transmission lines in the power grid. We want to record the interview, if you are not comfortable with that please let us know, and we will only take notes. Again, we thank you for taking the time out of your day to speak with us.

Questions

- Can you tell us a little about your current role and responsibilities?
- How long have you been at your current job?

Technical

- As you know, we are curious to find out about potential upgrades to the grid in Switzerland, so perhaps we can jump right in by asking you if you would explain why you think the grid does or does not need major upgrades.
- Clearly there are many different technological options for upgrading the grid. What options do you think are most promising and why?
    - What are the benefits and downfalls of placing cables and GIL underground?
    - What are your main concerns with using overhead lines? What are the people's concerns?
    - We know that sometimes the government will ask the companies to make an analysis of using different options for the projects, what are your thoughts on those studies?
    - Do you think this is an efficient way of analyzing the situation, and how can we make it better?

Social

- We've been hearing a lot about the Yverdon-Galmiz project, Can you tell us a little more about the project and where it stands now?

- What outcome are you expecting?

- What are your thoughts on the Chamoson-Chippis outcome?
- Are there any other projects being objected to by Environmental groups at the moment?
- Do you think that selling the electricity to other countries has a role in how people look at the projects?

Political

- What is the federal government doing to promote grid upgrades and is there a consensus among the parties about how to proceed?
- What are your legal rights for preventing a project you believe will do more harm than good?
    - What role do the cantons play in supporting or opposing grid upgrades?
    - Can you appeal the court's decision?

Financial/economic

- We know one of the major concerns about using cables and GIL's are the costs, how much do you see prices rising with using different options?
    - How will the upgrades be financed?
    - Do you think a cost increase in utility bills is something people will be okay with?

Sign off

Thank you again for taking your time to speak with us. We really appreciate it. We were wondering if we could contact you later if we have more questions. Who else should we talk with to get better insight?

Appendix D

Research and Academic Institutes Script

Preamble

Hello, we are students from Worcester Polytechnic Institute here working on a project. We would like to ask you some questions about electrical transmission lines in the power grid. We want to record the interview, if you are not comfortable with that please let us know, and we will only take notes. Again, we thank you for taking the time out of your day to speak with us.

Questions

- How long have you been at the institute?
- Can you tell us a little about your current role and responsibilities?

"As you know, we are curious to find out about potential upgrades to the grid in Switzerland, so perhaps we can jump right in by asking you if you would explain why you think the grid does or does not need major upgrades."

- Increasing demand and aging infrastructure
- What specifically needs to be upgraded with the transmission system?
- Can you share the leading projects to upgrade the transmission grid?
- How do you think the efficiency of the transmission system can be improved?
- We know that there are many sources of energy, which is the leading?
- With Germany upgrading its transmission grid, how is that affecting the Switzerland's decision?
- Can you tell us a little more about how Energy Strategy 2050 may drive grid upgrades?

"Clearly there are many different technological options for upgrading the grid. What options do you think are most promising and why?

- What are some of the technology options for upgrading the grid?

- Underground vs. Overhead lines
    - GILs vs. regular cables
    - Gas Insulated Switchgear
- Are underground transmission lines feasible as an alternative to overhead transmission lines?

"What are some of the key barriers or obstacles that have to be overcome in order to upgrade the grid and how do you see these playing out in the future?"

- Social
    - Can you tell us how important is the public opinion in the decision making process?
    - How concerned are the people about this issue?
    - How has the debate about grid upgrades played out in the public arena?
    - What concerns have members of the public raised, if any?
    - What are the major opposition groups?
    - What strategy is your company following to win public support?
- Political
    - What is the federal government doing to promote grid upgrades and is there a consensus among the parties about how to proceed?
    - What role do the cantons play in supporting or opposing grid upgrades?
    - How are other countries faring with expanding their transmission grids? Are they using cables?
- Financial/economic
    - How will the upgrades be financed?

Sign Off

Thank you again for taking your time to speak with us. We really appreciate it. We were wondering if we could contact you later if we have more questions. Who else should we talk with to get better insight?

Appendix E

Regulatory and Permitting Agencies Script

Preamble

Hello, we are students from Worcester Polytechnic Institute here working on a project. We would like to ask you some questions about electrical transmission lines in the power grid. We want to record the interview, if you are not comfortable with that please let us know, and we will only take notes. Again, we thank you for taking the time out of your day to speak with us.

Questions

- Can you tell us a little about your current role and responsibilities?
- How long have you been at your current job?

"What are the policies and regulations of expanding the electrical power grid?"

- What are some of the political and regulatory issues related to the expansion?
- What is the federal government doing to update and expand the grid?
- How is the government financing the upgrades of the grid?
- How does the Energy Strategy 2050 play out in terms of grid upgrades?
- Do these policies vary from canton to canton?
- How are the policies decided?

"What was the hierarchy of the decision process to decide which new lines to create?"

- What is the process of installing new lines?
- How are decisions made about where to route a new transmission line?
- What types of environmental concerns do you consider in evaluating routes?
- How does the court resolve which overhear or underground lines to install?

- We are aware that it takes many years decide on new power lines projects. Are there plans to modify the decision process to shorten this time?
- How does the decision making process for new lines differ based on the cantons?

"When there is great opposition between the utility companies and the environmental groups, how do the courts settle the conflict?"

- Have the cantons and political parties have reached consensus on a way forward. If not what and where are some of the differences?
- Is there an appeal process for the party that is not satisfied with the outcome of the court's ruling?
- What are some recent cases where there was great position?
- How do the people react the court's final decision?

Sign Off

Thank you again for taking your time to speak with us. We really appreciate it. We were wondering if we could contact you later if we have more questions. Who else should we talk with to get better insight?

Appendix F

Cable Manufacturing Companies

Preamble

Hello, we are students from Worcester Polytechnic Institute here working on a project. We would like to ask you some questions about electrical transmission lines in the power grid. We want to record the interview, if you are not comfortable with that please let us know, and we will only take notes. Again, we thank you for taking the time out of your day to speak with us.

Questions

- Can you tell us a little about your current role and responsibilities?
- How long have you been at your current job?

"Could you speak to the concerns some people have that living under high voltage lines is unhealthy?"

- The Swiss are very proud of their cows, but could EMF be harmful to animals and wildlife as well as humans?
- People certainly seem to have less opposition to installing an Underground network. Could you speak to the possible health risks associated with living near underground Cables?
- How does a buried cable's EMF compare to that of an overhead high voltage line?
- As a cable manufacturer, what are you trying to do to reduce EMF and the possible health risks?

"Can you speak to the environmental concerns associated with the use of underground cables?"

- A buried cable produces heat, and can heat and dry out the ground around it. How can this effect be dealt with?
- How much does your company work with environmental groups regarding the production and use of cables?

"The high cost of cables is a major deterrent from the technology. What is your company doing to try to reduce the production costs of these cables?"

- Of course underground installation is expensive as well, do you have any ideas of how to bring the installation cost down as well?

- What are some things your company is trying to do to improve the life cycle and reduce maintenance costs of cables?
- Cables have a relatively short range when compared with overhead lines and other technologies such as GIL. How is your company trying to address these issues?
- The infrastructure required to connect sections of underground cables to the overhead grid is costly and has a large footprint on the land. Is there a way to reduce this cost and physical area?

"How are other countries like Germany dealing with these issues?"

Sign Off

Thank you again for taking the time to speak with us, we really appreciate it. We were wondering if we could contact you later if we have any further questions. Also, do you know of anyone who you think could be beneficial to our project? We are always looking for more contacts to fill out our research.

Appendix G

Siemens Interview Script

Preamble

Hello, we are students from Worcester Polytechnic Institute here working on a project. We would like to ask you some questions about electrical transmission lines in the power grid. We want to record the interview, if you are not comfortable with that please let us know, and we will only take notes. Again, we thank you for taking the time out of your day to speak with us.

Questions

- Can you tell us a little about your current role and responsibilities?
- How long have you been at your current job?

- What are the benefits of using GIL's instead of cables and Overhead lines?
  - Do GILs have less power loss than lines/cables?
  - How do GIL maintenance costs compare to those of Cables?
  - What about the installation costs between GIL and cables?
  - What are the manufacturing costs?
  - What's the environmental imprint from using the materials to manufacture GIL's?
  - When a customer approaches you for different options, do you do an analysis for the customer of all the available options?
- We know Gil is still a developing technology, are you working on a third generation of GIL's?
  - Are you trying to get the costs of GIL down?
  - In the future will you be able to make more GIL underground for the transmission systems?
  - How soon do you think your cost reduction projects will come to fruition?
- We know Switzerland isn't using GIL as much as other countries like Germany and even Austria, what do you think is the reason for that?
  - Do you know of any other projects that use GIL?

  - Where do you see GIL fitting into the Swiss/European systems?
  - Do you have any customers from Switzerland looking to do a project with GIL in the near future?
- SF_6 is highly regulated – are there any specific policies regarding how much SF_6 can be used?
- Could you tell us a little bit about GIS?
  - Can GIS be used with Cables and Overhead lines as well?
- Are there any groups that oppose GIL?
  - DO you think that environmental groups will have an issue with the gas inside GIL if they're used in Switzerland?

Sign Off

Thank you again for taking your time to speak with us. We really appreciate it. We were wondering if we could contact you later if we have more questions. Who else should we talk with to get better insight?