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Enabling Sustainable Electricity Grid Infrastructure in Europe - Strategies and Challenges in Austria and Switzerland

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Affidavit

I, **MARIJA PISAREVIC, BSC**, hereby declare

1. that I am the sole author of the present Master's Thesis, "ENABLING SUSTAINABLE ELECTRICITY GRID INFRASTRUCTURE IN EUROPE - STRATEGIES AND CHALLENGES IN AUSTRIA AND SWITZERLAND", 60 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
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Abstract

The European electricity infrastructure is essential for a successful energy transition in the future. In that sense, a well-functioning cooperation framework that sets common priorities is indispensable for enabling a sustainable electricity grid. However, planning and permitting procedures are complex undertakings due to various technical, environmental, and legal considerations, mainly on the national level, and extensive scenario analyses and significant interdependencies on the transnational level. By analysing the common cooperation framework on the European level and its relations to the country-specific strategic approaches of Austria and Switzerland, this thesis examines conflicting and common priorities towards reaching the overall goal of a secure, reliable, and sustainable future electricity supply.

Table of Contents

Abbreviations

AC
Alternating current

APG
Austrian Power Grid AG

CTO
Chief Technical Officer

DC
Direct current

EC
European Commission

ELF
Extremely low frequency

ENTSO-E
European Network of Transmission System Operators for Electricity

ES 2050
(Switzerland's) Energy Strategy 2050

EU
European Union

HVDC
High-voltage direct current

IARC
International Agency for Research on Cancer

ICNIRP
International Commission on Non-Ionizing Radiation Protection

IEA
International Energy Agency

kV
Kilovolt

NDP
Network Development Plan

NSI East
North-South Interconnections in Central Eastern and South Eastern Europe

NSI West
North-South Interconnections in Western Europe

μT
Microtesla

PCI
Project of Common Interest

RES
Renewable energy systems

SFOE
Swiss Federal Office of Energy

TSC
Transmission System Operator Security Cooperation

TSO
Transmission System Operator

TWh
Terawatt-hour

TYNDP
Ten-Year Network Development Plan

UN
United Nations

VUEN
Vorlarlberger Übertragungsnetz GmbH

#mission2030
Austrian Climate and Energy Strategy

1 Introduction

To avert and limit environmental damage induced by the climate crisis, increasing efforts are made regarding the reduction of greenhouse gas emissions from fossil fuel generated electricity, through reorientation towards renewable energy systems and a decarbonized electricity supply. International, intergovernmental, and national objectives that have been set in recent years clearly represent these current ambitions and show that the electricity industry is confronted with substantial changes. In Europe, there is consensus that the modernization of **the electricity grid is of fundamental importance** for a successful power supply in the future. Consequently, the electricity network requires a comprehensive adjustment not only to current changes but also to future needs. This raises various challenges for grid operators since the grid must be planned according to a prospective supply task that is based on long-term estimations and scenarios.

The development of the grid depends on country-specific circumstances that relate to the electricity industry and stem from historical, geographical, and political characteristics. These lead to different strategic approaches regarding the planning of the electricity infrastructure. At the same time, many issues can be resolved in a more favourable way when countries work together, as the grid does not stop at national borders. Europe, therefore, strives to integrate the electricity market and interconnect its grid to make it more efficient and resilient for the benefit of all. However, countries still have their own priorities and constraints when it comes to the implementation of power line projects.

By and large, all these aspects are linked to the **energy transition**. The energy system, including the electricity system, is facing a major transformation, although the combination of primary energy sources that is used to meet our energy needs, referred to as the energy mix, is only slowly changing. Primary energy sources are still dominated by fossil fuels and their use in the generation of electricity is even expected to increase in the upcoming years but, eventually, the transition to a low-carbon economy should take place. Renewable energy systems aim to become the leading technology and a generally more sustainable electricity generation is envisaged.

This includes a major conversion of the power grid and requires its timely development, because the planning of linear infrastructure can take up to decades. The renewable energy systems that are necessary for reaching the climate goals can only be implemented if the grid capacity is able to integrate them into the system. In 2018, 26 percent of global electricity generation stemmed from renewables, according to the IEA (n.d.). There are different scenarios that are based on diverse estimates, but they all have in common that the share of renewable electricity will increase. Other aspects in relation to the energy transition that call for a further grid development will be described in the next subchapter in more detail.

Sustainability has many dimensions. What is considered sustainable when referring to electricity infrastructure can depend on the perspective, although a holistic approach should be pursued. In general, socio-economic and environmental considerations need to be balanced out, while taking technical considerations into account. Since this can lead to different results, the planning of a sustainable grid is essentially a task that encompasses many diverse stakeholders and their respective interests. At this point, I will stress the cooperation between countries again, as, in the context of sustainability, a well-functioning international cooperation is an essential factor that enables not only more favourable solutions for the individual countries, like mentioned before, but also more sustainable ones.

Different organisations describe sustainability concerning the electricity grid in similar ways. For Swissgrid, Switzerland's TSO, a sustainable grid modernisation is *"technically secure"* and *"as environmentally friendly and economically efficient as possible"* (Swissgrid 2015b, 15). This formulation implies that technical considerations are indispensable, while economic and environmental aspects can only be considered to a certain extent. As some of the desired objectives overlap or contradict each other, a balance must be found, and trade-offs need to be made.

Referring to the **grid development in the last decades**, in Austria, a crucial part of the grid, namely all 380 kV transmission lines, developed only after 1975. Prior to that, 220 kV lines were the rule (APG 2013, 25). If we look at the development of the grid infrastructure in the past decades in Switzerland, we see that it has slowed down. According to Swissgrid (2015b, 15), only a third of its almost seven thousand kilometres of grid length dates from after 1980. Two distinct aspects arise from these facts: first, that most of the grid was not designed for the demands that arose in recent decades; and second, that grid operators increasingly need to deal with an aging infrastructure.

1.1 Context

1.1.1 Energy Transition

As stated before, it is generally agreed that grid development is of fundamental importance for the electricity industry. To answer the question why the modernization of the electricity grid and, in certain cases, new power lines are essential prerequisites for the energy transition, this subchapter will describe three influencing factors. Thereby, the relation between the electricity infrastructure and the energy transition will be discussed.

First, the **electricity demand** has grown over recent years and generally shows an increasing trend. As further increases are expected and the amount of electricity that is fed into the grid always equals the current consumption, the existing grid capacity is required to adapt to these changes. According to the IEA (2019), CO_2 emissions from the power sector reached a record high in 2018 and the major cause for this development is the rising electricity demand. There are several reasons for this trend: household incomes are rising; the transport and heating sectors are experiencing increasing electrification; and the demand for both digital connected devices and air conditioning is growing (IEA 2019). In general, the changing behaviour and preferences of users gained importance and require careful consideration not only in demand forecasts but also concerning the design of economic frameworks and legal regulations.

Against the general trend, IEA's Global Energy Review 2020, published in April 2020, shows a temporary decline regarding electricity demand in the context of the COVID-19 crisis' impacts on both energy demand and carbon dioxide emissions on the global level. The exceptional pandemic situation caused lockdown measures that lead to substantial decreases in global electricity demand. According to data that was collected from countries that represent over one-third of global electricity demand, IEA finds that, on average, one full-lockdown-month induced demand reductions of over 1.5% on an annual basis. This is explained by the fact that reduced commercial and industrial demand exceeded increases in residential demand. The stringency and duration of lockdowns has an essential influence on these demand reductions. Concerning the energy mix, as the output of renewables is not directly affected by demand, the recent demand reductions have temporarily increased the relative share of renewables in electricity supply, which leads to the next influencing factor. (IEA 2020b)

Second, the relative **share of renewables** in the energy mix has been increasing due to efforts to reduce emissions from fossil fuel generated electricity. Consequently, grid development is indispensable because more renewable energy systems will require integration into the grid and managing variable energy sources will become more challenging due to fluctuations in power output. The bigger the share of renewable energy that is fed into the grid, the more fluctuations must be handled. Moreover, electricity infrastructure is essential since it enables renewable energy to be generated at locations where conditions for energy output are optimal, even though it may be far from where the electricity is finally consumed.

According to an IEA publication that addresses policy makers concerning wind and solar PV technologies, different measures, depending on the phase in which the country finds itself, should be taken to integrate variable renewable energy into the system. Four stages of variable renewable energy deployment with different measures for the maintenance of both cost-effectiveness and reliability of the power system were defined. In stage one, there is no noticeable impact on the power system due to variable renewables. Austria, for example, is assumed to be in stage two, where a noticeable impact can be observed and, generally, most countries today are in one of the first two phases. In stage three, significant integration challenges arise, as the variability affects the overall system operation and other power plants, and the ability to respond to uncertainty becomes crucial. In stage four, highly technical new challenges occur and the focus is on maintaining the stability of the system in case of events that can disturb the operation on very short timescales, in the range of seconds. (IEA 2017)

Reliability and security in the supply of electricity must be ensured through grid development that is designed to manage the increasing share of renewables. Not only new opportunities but also new energy security dilemmas, due to the changed energy mix, for the energy transition emerge when renewables become cheaper and advances in digital technologies are made. According to IEA scenarios, wind and solar PV are responsible for either half, in the *“Stated Policies Scenario”*, or almost all, in the *“Sustainable Development Scenario”*, of the additional electricity generation in the upcoming two decades, by 2040. (IEA 2019)

Third, the electricity economy has been transforming due to a range of **electricity market developments** that favour competitiveness. Legal and institutional changes in the system call for adaptation and optimisation of the electricity grid. With efforts towards unbundling, a profound reorganisation of the European electricity market, Europe has enabled electricity trade to take place in a less restricted way which led to the emergence of both new tasks and new challenges for the transmission network. Initially, cross-border interconnections had the task to assist in case of malfunctions and provide for balancing, however, their new major task is to enable the transmission of internationally traded electricity (APG 2013, 15).

Overall, more frequent **congestions** are expected, which is a combined effect of the three influencing factors that were discussed. Therefore, ensuring the stability of the grid is expected to become more demanding. Not only a higher grid capacity but also better congestion management will be required in the future. For instance, Switzerland already experiences structural congestion in its transmission network due to rising overall demands. As this trend is likely to continue in the future and endangers both the supply security and economic efficiency of the Swiss electricity system, compensation measures are necessary (Swissgrid 2015b, 15). Regarding the increasing share of renewables in the energy mix, short-term measures and adjustments due to the variability are needed more frequently and may require a different design and adapted regulations. As an example, in 2018, there were more than 300 unpredictable interventions into the operation of the Austrian grid in order to ensure its stability, and the number of interventions increases annually (Freudenthaler et al. 2019).

1.1.2 Austrian and Swiss Perspectives

From an **Austrian perspective**, despite many political statements that have been made in this context, the CTO of Austrian Power Grid AG, Gerhard Christiner, finds that Austria’s current grid infrastructure is not prepared for the energy transition. Concerning the influencing factors mentioned in the previous chapter, the electricity demand of Austrians increases by about 1.5 percent per year and, according to the Executive Director of E-Control, the regulatory authority for Austria’s national gas and electricity market, Andreas Eigenbauer, the realistic share of renewable energy in 2030 in Austria is slightly below 90 percent. The current rate of expansion of renewables is about 1 TWh per year and this rate needs to be tripled to 3 TWh per year to enable the achievement of #mission2030 goals, which he finds to be technically and economically feasible. (Freudenthaler et al. 2019)

According to the current national Network Development Plan, the implementation of power line projects, and thereby increasing the grid capacity, is a prerequisite for both the energy transition and the goals of the Austrian climate and energy strategy #mission2030. Therefore, four crucial areas of focus were defined: first, the integration of renewables into the grid; second, the maintenance of the existing high level of security and reliability of power supply, which the consumers are accustomed to; third, to sustain the grid and system security; and fourth, the further development of the electricity market. (APG 2019, 11)

From a **Swiss perspective**, Swissgrid Ltd, Switzerland's national grid company, analysed direct and indirect driving factors that influence its grid and identified three direct and several indirect ones, that have an impact on the first-mentioned. If grid overloading occurs, at least one of the direct driving factors is responsible for the incident and measures to eliminate structural weaknesses can be directly attributed to them. The first direct driving factor is the emergence of new power plants in Switzerland. For example, a new large pumped storage facility can change regional electricity transport conditions to a high extent and cause overloading of the grid, which is particularly a risk in thinly populated areas with only a few strong lines. The second direct driving factor relates to international considerations due to electricity exchange with neighbouring countries that, on the one hand, improve Switzerland's supply security, but on the other hand, can cause an overloading of the grid due to increasing volumes that are traded. This is especially important in winter, when domestic production is low, and imports are needed. The third direct driving factor are the constantly required adjustments of the distribution grid. They can arise either as a result of changes in electricity demand and generation or, for example, due to new connections that can cause structural congestion. (Swissgrid 2015b, 16)

Swissgrid claims that "conditions underlying the conversion and expansion of the Swiss grid are unique" and that they "cannot be transposed from other countries" (Swissgrid 2015b, 16). In contrast to that, even if the entirety of conditions that affect the electricity infrastructure cannot be directly transposed from country to country, to a certain extent, they do overlap, and they can manifest themselves in similar strategical approaches. Therefore, country-specific conditions that influence national approaches will be analysed in chapter three in more detail. Prior to that, technical and environmental considerations about the transmission network will be discussed in chapter two.

1.2 Research Questions

The objective of this thesis is to outline the European planning framework and its institutions and organisations related to transnational cooperation that aim to enable a sustainable transmission network in Europe. Furthermore, Austrian and Swiss national strategic approaches and priorities concerning further grid development will be analysed in the context of the cooperation framework and their future role therein.

Therefore, the thesis addresses the following two main research questions:

What is the current framework for transmission grid infrastructure planning in Europe?

&

What are the future roles of the Austrian and the Swiss transmission networks in the context of a sustainable electricity infrastructure across Europe?

1.3 Structure of the Thesis

After the introductory discussion on why grid development is essential for the energy transition, the second part of this thesis will cover technical and environmental considerations regarding the implementation of transmission line projects that are relevant for the national planning and approval procedures.

The third and main chapter will provide an overview of the framework for cooperation on electricity infrastructure development in Europe by describing not only the legal framework but also the tasks and responsibilities of organisations involved in the planning process. Moreover, Austrian and Swiss strategic approaches regarding the further development of their transmission grid will be analysed in relation to the common European strategy.

1.4 Methodology

The European planning framework will be outlined according to the latest legislative and project-specific developments. Planned grid projects will be considered from both the European and national perspective to develop an understanding of their role and contribution to an overall sustainable European electricity grid.

To get an insight into the national strategical approaches and analyse the national perspectives and priorities related to the future role of the Austrian and Swiss transmission grid in Europe, the main information was gathered from the respective energy strategies and latest national grid development plans. Moreover, scenarios for future developments that affect both countries were considered on three levels: first, on international level from IEA documents; second, on European level from ENTSO-E documents; and third, on national level from national strategic plans.

2 Technical and Environmental Considerations

This chapter will cover technical and environmental aspects that influence the planning and implementation of transmission lines. Basic technical considerations regarding power lines, such as voltage levels and grid development terms, will be explained. Furthermore, environmental implications of electric and magnetic fields, audible noise, landscape and land use, and biodiversity will be discussed.

2.1 Technical Considerations

In general, the power grid refers not only to transmission and distribution lines but also to electricity generating stations and transformer stations. However, this thesis will focus on linear infrastructure, particularly on transmission lines, which can be installed as overhead lines or as underground cables. The focus is on extra-high voltage overhead lines, since they are predominantly used for interconnections with neighbouring countries and, consequently, are of relevance for enabling European interconnectors and a sustainable electricity infrastructure in Europe.

2.1.1 Voltage Levels

Countries use different voltage levels for their power supply systems. In Europe, the highest AC transmission voltages are 380 kV, while in the US, they equal 765 kV. This voltage range is denoted as extra-high voltage. Above 800 kV, the term ultra-high voltage is used. For instance, in Russia, voltages of up to 1200 kV have been used for certain lines across Siberia. (UN 2006, 20) With bipolar systems, such as the ultra-high voltage direct current lines that are in use in China since 2010, power can be transmitted over several thousands of kilometres. Although there are plans for more of these lines in China and India, UHVDC transmission lines are not easily applicable, due to special requirements and restrictions. (Humpert 2012)

Both Austria and Switzerland have seven grid levels, from which four levels (level one, three, five and seven) are transporting the electricity and three levels (level two, four, and six) are transforming the electricity to the higher or lower voltage of the subsequent grid level and are thus referred to as transformer levels. In general, higher voltage levels are used for electricity transmission, while lower voltage levels are used for regional electricity distribution and connect substations to consumers. Grid level one, the extra-high voltage level, receives the electricity either directly from electricity generating power plants or from abroad. This level is used for electricity transmission across Europe because higher voltage allows electricity to be transmitted over long distances with relatively low losses. The following table shows an overview of grid levels and the corresponding voltages in Austria and Switzerland according to their respective transmission system operators.

Table 1 – Grid Levels in Austria and Switzerland

Grid Level		Austria	Switzerland
1	extra-high voltage	380 kV 220 kV	380 kV 220kV
2	transformer level	extra-high to high	
3	high voltage	110 kV	36 kV – 150 kV
4	transformer level	high to medium	
5	medium voltage	> 1 kV – 36 kV	1 kV – 36 kV
6	transformer level	medium to low	
7	low voltage	≤ 1 kV	< 1 kV

(APG n.d.b; Swissgrid n.d.b)

As countries must interconnect at the same voltage level, a common standard facilitates the interconnection. Therefore, the European 380 kV standard is crucial. Otherwise, transformers would be required to connect lines with different voltages, which can become economically inefficient if too many transformers are needed, since they are costly. If voltages differ only slightly, less expensive autotransformers can be used. (UN 2006, 27-28)

2.1.2 Overhead Lines and Underground Cables

Overhead electricity lines are predominantly used at the extra-high voltage level. They are installed above ground and consist of conductors and a supporting structure, either towers or poles. (Swissgrid n.d.c) When planning overhead lines, two basic decisions regarding the design need to be made. First, the determination of the size and the type of conductors is important for minimizing losses, costs, and weight. In most cases, conductors consist of aluminum wires that are reinforced with steel. Aluminum is used, as it is lighter and cheaper than copper. Second, the support structure and configuration of conductors need to be defined. This has an impact on the intensity of the electromagnetic field, which will be described in more detail in subchapter 2.2.1. (UN 2006, 24)

The electricity flow creates heat and the main advantage of overhead lines is that this heat can easily be transferred to the surrounding air, which acts as an insulator. This allows more electricity to be transported in winter than in summer, due to lower temperatures. (Swissgrid n.d.c) Temperature limits generally determine the capacity of overhead lines. Faults and damages can occur if the lines exceed the limit, since excess sag can either lead to contact with surrounding objects or loss of tensile strength of the line. If tensile strength is lost, the original length of the line cannot be reached again. Temperature limits require more attention than in the past since the lines experience a higher capacity utilization due to the increasing trend in electricity trade. In this regard, ampacity, measured in amperes, refers to the conductor's capacity to carry current while remaining below thermal limits. (UN 2006, 24-28)

Underground cables are predominantly used in densely populated areas, e.g., urban areas. They need to be insulated and, additionally, cooling systems are often required to dissipate heat that is created by the electricity flow. As the higher costs of copper, the better conductor, can be compensated by lower resistive heating and the better conductivity, it can be used instead of aluminum. (UN 2006, 24)

For instance, Swissgrid uses underground cables for voltages up to 150 kilovolts. Regarding the construction, there are two options: one with and one without trenches. Either a wiring trench with a width of approximately five meters is used, where concrete tube blocks are placed at approximately one to two meters depth, or tunnels with a diameter of three to four meters and cable holders inside are constructed. The first option requires a width of at least 25 meters. (Swissgrid n.d.c)

Concerning the planning of transmission line routes, project planners and engineers consider combinations of overhead lines and cables along a line to be challenging, since cable transfer stations are needed for the transfer between the different technologies and these stations cover a large area. As structural conditions need to be considered and existing traffic infrastructure should be avoided, positioning cable trench routes and cable transfer stations is a key task. (Swissgrid n.d.c)

2.1.3 Optimization, Reinforcement and Expansion

When referring to the development of the grid, different terms are used to refer to the possible types of action. This subchapter will describe possible technical implications of the different grid development options: grid optimization, grid reinforcement and grid expansion. Synonyms, such as grid modernization, grid upgrade and grid strengthening, are commonly used as well. The three terms that were chosen to be described here stem from German transmission system operators' "NOVA-Prinzip" (APG 2019, 24). This principle prioritizes the three options for grid development*.* *"NOVA"* is the German acronym for *"Netz-Optimierung vor Verstärkung vor Ausbau"* which can be translated as: grid optimisation before grid reinforcement before grid expansion.

Although the term stems from German operators, the strategies of both Austria and Switzerland refer to this principle. For instance, the Austrian Network Development Plan, that will be analysed in more detail in subchapter 3.2.4, clearly states that – concerning sustainable considerations regarding the performance of transport capacities, environmental compatibility and national economy – APG follows the NOVA principle. The Austrian transmission system operator refers to operation management optimization, grid reinforcement, and grid expansion as the three options for action for enabling the energy transition. (APG 2019, 24-25) Swissgrid states that if grid development is necessary and economically meaningful for the Swiss economy, it should be implemented according to the NOVA principle and preserve the landscape as much as possible. Swissgrid refers to it as one of two main planning principles, whose purpose it is to keep the impact on the environment and the landscape as low as possible. (Swissgrid 2015a, 45-46).

Grid optimization measures aim to keep the performance of the existing transmission network at the highest possible level or rather to increase the performance (APG 2019, 44). Measures included in this category do not have visual impacts on existing lines. For instance, elimination of congestions at substations, construction of power factor correction systems, replacement of transformers to improve the short-circuit resistance, conversion of 220 kV lines to 380 kV lines on lines that are already adequately dimensioned and approved, and similar measures are considered in this category. (Swissgrid 2015a, 46) Grid optimization can also refer to adjustments in the context of demand response. Additionally, APG mentions the following measures for optimizing the operation of the grid: forecasting tools used by TSC, which will be described in subchapter 3.1.3; exchange of online data and monitoring; and a coordinated redispatch. However, APG finds that the potential of these measures is largely exhausted. (APG 2019, 25)

The aim of **grid reinforcement** is to strengthen existing lines. Thus, reinforcement measures relate to investments in existing infrastructure, both transformer stations and lines. These grid investments are likely to increase in the future. Strengthening existing transformer stations, e.g., concerning the short-circuit resistance, can lead to general refurbishments or replacement constructions in the sense of a technical and economic optimization. (APG 2019, 44) This second NOVA principle category is comprised of measures that have visual impacts and can be perceived from the outside but do not require new routes. Examples of such measures are: conductor replacement to conductors with higher transmission capacities including increasing the ground clearance; changes concerning the conductor size; expansion of substations; deployment of high-temperature conductors; and conversion of a line, e.g., from 220 to 380 kV. (Swissgrid 2015a, 46) APG mentions similar measures in its Network Development Plan 2019, however, it also states that grid reinforcement measures have a limited potential and their planning and implementation needs to be facilitated (APG 2019, 25).

Grid expansion aims to extend the transmission network and connect previously not interconnected points. Thus, it refers to new power lines on new routes and also new substations, which should only be planned if optimization or reinforcement measures do not suffice (Swissgrid 2015a, 46). In this category, APG additionally mentions HVDC corridors, a technology that is currently primarily used as undersea cables in Europe, in the context of connecting to wind offshore parks in the north. APG claims that grid expansion measures offer a great potential for the further integration of renewable energy systems. (APG 2019, 25) Although grid expansion measures are often the more appropriate solution for solving network planning issues, they entail more environmental impacts than optimization or reinforcement measures and are thus considered as the last resort. Due to these environmental concerns, they are prone to public opposition and creating of public acceptance is a key challenge. However, expansion can also be considered as indispensable for achieving our climate goals and a successful energy transition.

2.2 Environmental Considerations

Environmental aspects are often classified according to the realm that they affect – air, water, soil, humans, flora, and fauna. Distinguished by the time of occurrence and duration, implications of transmission lines on the environment can additionally be classified into: impacts during construction or during operation of transmission facilities; and short-term or long-term impacts. Furthermore, a subdivision according to the size of the affected area is possible and leads to a classification into local, regional, and global environmental impacts.

This chapter will discuss the following environmental impacts of linear electricity infrastructure, i.e., transmission lines, that require careful consideration in the planning process: electromagnetic fields and their potential effects on health, noise pollution, land and landscape considerations and impacts on biodiversity.

2.2.1 Electric and Magnetic Fields

Electric and magnetic fields, often referred to as electromagnetic fields, are one of the main environmental aspects that need to be considered in the planning process of power lines, since they can have health impacts on people that live and work in the vicinity of the power line (UN 2006, 118). They occur wherever electricity is generated, transported or used.

The basic **difference** between the electric field and the magnetic field is that regardless of if an electric device is switched on or off, an electric field is produced as soon as the device is connected to the power socket and voltage is carried. An additional magnetic field occurs only when the device is switched on and current flows. Electric and magnetic fields can be either static or alternating, depending on whether they relate to a direct or alternating current. Static fields have a constant strength and occur with, for instance, computers, phones, and other conventional electronic devices, whereas alternating fields have a changing voltage and current intensity. (Swissgrid n.d.a)

What influences the **strength of the fields** are the current intensity and the distance to the conductor. The current intensity defines the strength of the magnetic field around a power line, which is measured in microtesla μT. The lower the current intensity, the less intense is the magnetic field. To mitigate risks in case of a power line failure, the capacity of extra-high-voltage lines is usually not fully exhausted, so that other lines can be used for the current flow. Concerning the intensity of both electric and magnetic fields, the distance to the conductor or cable is crucial since the intensity declines with distance. Magnetic fields from overhead power lines are in the range of a few microtesla when they reach the ground, whereas magnetic fields from underground cabling can reach up to one hundred microtesla. Thus, the intensity of magnetic fields is much higher right above underground cabling than below overhead lines. (Swissgrid n.d.a)

Potential adverse **health impacts** due to electromagnetic radiation are the reason why limits were determined. For that purpose, we need to clearly differentiate between electric and magnetic fields. Our skin and clothes largely prevent electric fields from entering the body. However, magnetic fields can penetrate not only walls but also the body, which is why exposure limits are required to prevent sufficiently strong fields from influencing biological signals. (Swissgrid n.d.a)

International limits and recommendations exist with the purpose to prevent negative health effects. Discussions about health consequences from exposure to extremely low frequency electric and magnetic fields started in the late 1970s and initiated research activities that tried to answer the question about the existence or non-existence of such consequences (WHO 2007a). In 2002, IARC, the International Agency for Research on Cancer, concluded that extremely low frequency magnetic fields, such as the fields in the proximity of transmission lines, are *"possibly carcinogenic to humans"*, while static magnetic fields and ELF electric fields were not assigned this property (IARC 2002, 338). However, in 2007, scientific experts revised this evidence concerning cancer and analysed additional health effects, other than carcinogenic. Their conclusions and recommendations can be found in a special publication concerning environmental health effects of extremely low frequency fields (WHO 2007b). Overall, they concluded that the evidence that was used for the publication in 2002 and relates to childhood leukaemia is not strong enough, and therefore, cannot be considered as causal. For other health effects that were additionally analysed, such as cardiovascular disorders or immunological modifications, the evidence was found to be even weaker. Most European countries follow the exposure limit guidelines of ICNIRP (1998), the International Commission on Non-Ionizing Radiation Protection. (WHO 2007a)

Switzerland claims that its limits are “among the strictest in the world” and ”one of the strictest limits in Europe” (Swissgrid n.d.a). The 100 microtesla exposure limit “protects against all scientifically known adverse health effects” and is therefore generally applicable where people may be present (Swissgrid n.d.a). Additionally, the Environmental Protection Act in Switzerland states that the population requires protection from risks to human health that are conceivable, but not yet proven. Therefore, the installation limit of 1 μT that applies where people spend longer time periods, e.g., living rooms and playgrounds, has been defined. (Swissgrid n.d.a) The installation limit is defined in the ordinance on the protection from non-ionising radiation, *“Verordnung über den Schutz vor nichtionisierender Strahlung”*, which entered into force in February 2000 (Der Schweizerische Bundesrat 2019).

In Austria, "precautionary limits are not formally advised" but the authorities "usually require compliance with a maximum magnetic flux density of 1 microtesla (1% of the reference level in the EU recommendation), derived from Swiss legislation" (RIVM 2018, 5). In more detail, the former valid standard *ÖNORM E 8850*, published in 2005, complied with 1998 ICNIRP reference values, which were stricter than the revised reference values from 2010 (Österreichs E-Wirtschaft 2014). The new guideline refers to the revised values. Austria’s *OVE-Richtlinie R 23-1*, a technical guideline by OVE, the Austrian Association for Electrical Engineering (*Österreichischer Verband für Elektrotechnik*) about electric and magnetic fields replaced the *ÖNORM E 8850* in April 2017. However, in Austria, these guidelines are not legally binding, and the reference values are not incorporated into a national law. Compared to the reference values that are considered in Austria, Switzerland has stricter and legally binding limits.

2.2.2 Noise

High-voltage lines can emit audible noise. Environmental concerns regarding noise relate to electrical discharge that occurs locally in transmission lines and produces noises such as a crackling or humming. This process is called corona discharge and the resulting audible noise is only relevant for overhead lines since they are primarily caused by unfavourable weather conditions. Thus the noise does not occur with underground cables. The implementation of a grid reinforcement measure that upgrades a line from 220 kV to 380 kV leads to an increase in the noise level. In Switzerland, the legally determined emission limit in residential areas is 55 decibels at day and 45 decibels at night. These limits are very strict, since the noise pollution from a busy street, for example, can be more than 80 decibels. (Swissgrid n.d.a) Furthermore, the Swiss limits comply with the recommended values in the context of preventive health protection by the WHO in the *"Guidelines for community noise"* (WHO 1999). Switzerland has uniform and legally binding standards on federal level, whereas in Austria, there are no legally binding noise limits, which is prone to conflicts and calls for regulatory improvements (Arora 2018).

2.2.3 Landscape and Land Use Considerations

Generally, linear infrastructure is particularly challenging when it comes to finding the optimal route. Land use and landscape considerations require to be considered in this process from the beginning. In the context of transmission lines, the visual impact and the disturbance of the landscape must not be neglected. Changes in the landscape are often highly important for the locals. Consequently, landscape conservation and preserving aesthetic values are significant for decision-making concerning the planning of the route and for the creation of public acceptance. Moreover, regarding the land use, transmission lines have a strong impact on spatial planning due to land use reservations and restrictions for other purposes.

Furthermore, this topic remains important throughout the operation phase. For instance, concerning transmission line corridors, the Austrian Power Grid differentiates five main corridor types according to the characteristics of the landscape that they traverse. Both natural and cultural aspects of the landscape are considered. The management of the lines depends on these five main types, which in total have twelve subtypes: first, lines above the timber line; second, forest dominated lines; third, grassland dominated lines; fourth, cropland dominated lines; and fifth, lines in settlement or industry areas. For each of the different types, there are respective guiding principles that cover the ecological characteristics that need to be considered. (APG 2019, 107)

2.2.4 Biodiversity

Concerning biodiversity, transmission lines have potential impacts on flora and fauna in the area of the power line, which applies for both the construction and operation phase

(UN 2006, 118). In general, environmental impacts of linear infrastructure can be similar regarding power lines, pipelines, roads, and railways. For instance, loss, fragmentation, or alternation of species' habitats is often attributed to linear infrastructure and strongly affects ecosystems by disrupting the landscape connectivity. However, there are also risks that only relate to power lines, such as electrocution. Therefore, studies in the context of power lines often focus on bird electrocution through collision with power lines but information about the magnitude of the environmental impacts remain unknown. Concerning impacts on plants, most power line studies focus on how changes to plants influence birds and mammals rather than addressing solely the impact on plant communities. One of the recommendations for the planning of power lines to mitigate the environmental impact on biodiversity is to avoid underground cables. Overall, for designing sustainable linear infrastructure that considers the mitigation of impacts on biodiversity, improving the cooperation and data exchange between scientists and corporations is required. (Richardson et al. 2017)

2.3 Interim Conclusion

Overall, technical and environmental considerations substantially affect the planning of a sustainable grid since they can facilitate or hinder the implementation of power line projects according to the optimal route. On the one hand, the more grid expansion is needed, the more environmental concerns arise and the greater is the spatial area that is affected by the new lines, which is why reinforcement should be preferred wherever possible if optimizing the grid operation is not sufficient. On the other hand, due to economic considerations, expansion is likely to be preferred as it is often more efficient in an economic way. Furthermore, considering the influencing factors that were discussed in the introduction, expansion can be indispensable due to the non-existence of interconnections that are required to successfully perform the new supply task. However, route planning and decision-making is a complex task that involves various interests and puts cooperation in the focus of attention, to enable the most efficient and sustainable solutions. The aim of chapter two was to outline basic technical and environmental considerations that are unavoidable in both countries considered in this thesis, as they have high environmental standards, regardless of transnational challenges.

3 Transmission Grid Planning in Europe

For **enabling a sustainable electricity grid infrastructure**, cross-border considerations are essential. Both good engineering and cooperation between the interconnected systems across borders by “data sharing, joint modelling, and clear communication” throughout the planning and operation phases require focused efforts from all affected parties (UN 2006, 27-28). Regardless of the necessity of closer cooperation, countries implement national strategical approaches regarding their infrastructure that stem from geopolitical circumstances which all need to be considered in the development of common strategies concerning grid development.

The third section of the thesis will cover cooperation and integration efforts that aim to improve the European electricity grid infrastructure. Thereby, the European framework for the planning of a pan-European grid will be described. Furthermore, the role of the Austrian and the Swiss transmission grid in the European context will be analysed and their national objectives, legal framework, and planning instruments concerning the transmission network will be discussed.

3.1 European Planning Framework

This subchapter will analyse European strategic approaches concerning grid development by describing the grid planning process on the European level. Four areas will be discussed: first, the European objectives; second, the legal framework; third, institutions and organisations involved in electricity grid planning and their competencies and functions; and fourth, planning instruments that are used. European cooperation regarding the planning of the future grid is mainly coordinated through ENTSO-E, which was established by the European Commission. However, its scope is not limited to the EU, since ENTSO-E includes countries that are not member states of the European Union, such as Switzerland or countries in Southeast Europe. This is advantageous for all parties involved since political borders are less relevant for the further sustainable development of the continental grid.

In this sense, it should be noted that even though **Switzerland** is not a member state of the European Union and is thus not directly affected by EU's legislation packages concerning the electricity sector, it is indirectly affected by the changing circumstances in its neighbouring countries. Furthermore, EU's regulations are relevant for Switzerland, as it is currently negotiating an electricity agreement with the EU about the further integration into the common electricity market in the future. Implications for the Swiss transmission grid and its role in the context of the continental grid depend on the negotiation outcome.

3.1.1 European Interconnection Targets

Concerning the further grid development in Europe, one of the crucial benefits of better cooperation and stronger interconnections of not only markets but also infrastructure across Europe is that these efforts contribute to enabling an energy transition that is less costly for the European population (HBF 2018, 8). Furthermore, balancing electricity demand and supply requires a careful electricity grid management which benefits from functioning cross-border electricity exchange. The interconnection of individual national electricity grids, in this sense, enables a sustainable grid management, as it allows European countries to achieve better results in managing the challenging variability of renewable energy sources and their fluctuating power outputs that were discussed in the introduction. (HBF 2018, 24-25)

The **purpose of EU's interconnection targets** is to reach improved cross-border electricity interconnections and thereby increase security of electricity supply in the European Union. Interconnections enable the surplus electricity produced by renewables in one country to be used in another country and avoid switching off variable renewable energy systems when demand is low. Moreover, reliable connections reduce the risk of blackouts. (EC 2020a) European interconnection targets were set to be 10% by 2020 and 15% by 2030 and their achievement is essential for Europe in order to *"reap the full potential of its renewable energy sources while ensuring security of supply and competitiveness"* (EC 2017a, 15). In other words, each countries' electricity transmission line network should be able to transport at least 10% by 2020 and at least 15% by 2030 of the electricity produced within the country to its neighbouring countries. In the context of these targets, regular reporting from the European Commission on how to achieve the 2030 goal of 15% interconnectivity was demanded by the European Council. (EC 2020a) Therefore, the EC set up an expert group on electricity interconnection that provides technical advice regarding the implementation of required interconnections (EC 2016).

The **expert group's recommendations** were considered by the EC and included in its *Communication on strengthening Europe's energy networks.* This document recognizes the contribution of an interconnected European grid for ensuring not only secure and sustainable but also affordable energy for all Europeans. Furthermore, it assesses the progress towards achieving interconnection targets. Austria is one of the countries that has already reached its targets, as the interconnection level was 15% in 2017. The expected Austrian interconnection level for 2030 is 32%. Switzerland's interconnection level is implied to be above the set target as well, although no specific percentage was published that could be directly compared. However, as full commitment is required regarding transnational issues the EU *"calls upon Member States to prioritise the development of interconnections with those neighbours that are below any of these thresholds in a spirit of solidarity and cooperation"* (EC 2017a, 13). Several countries were expected not to fulfil the interconnection targets by 2020: Great Britain, Spain, Poland, Cyprus and Italy, which is the most relevant for Switzerland and Austria (ENTSO-E 2019e, 7). Comparing Austrian and Swiss neighbours, Germany has a relatively low interconnection level as well. In that sense, the implementation of missing infrastructure links is encouraged by the EC and, in addition, the importance of the realisation and application of internal market rules in the context of optimizing the operation of existing grid interconnections is highlighted in this document. (EC 2017a, 10-15)

Concerning the **interconnection levels' measurement**, the Expert Group concluded and recommended in the first report called *Towards a sustainable and integrated Europe*, that Switzerland and Norway should not be treated as third countries *"as these two countries are connected only to the EU electricity systems and do not have any other interconnectors with the electricity systems of third countries"* (EC 2017b, 28). However, it should be noted that Norway has "*a production-radial crossing the Russian border, connecting two Russian hydro power plants"* but it is not possible to connect the Norwegian to the Russian system (EC 2017b, 28).

Changes in measuring the interconnection level have been introduced in 2017, when the Interconnection Target Expert Group proposed a new methodology to replace the criteria for the 15% interconnection target by 2030. The new methodology uses the CBA methodology as a basis and focuses on three concepts: first, the interpretation of the efficiency of the internal energy market considers price differentials with and without the interconnection to prioritise between them; second, for every member state of the EU, peak demand is assumed to be met through both imports and national capacities; and third, concerning the further integration of renewable energy systems, not every member state is expected to integrate renewables through imports and national capacities combined and the option for additional interconnectors should be investigated. (ENTSO-E 2019a, 34)

When applied in the context of the TYNDP 2018, that will be further discussed in subchapter 3.1.4, the new methodology that was jointly developed by the Expert Group, the EC, ENTSO-E, the industry, experts and universities, shows that the most urgent additional interconnections in all 2030 scenarios are needed in Spain, Italy, Great Britain, Ireland, and Finland (ENTSO-E 2019a, 34).

3.1.2 Legal Framework

If we look at the **history of the EU legislation** concerning energy trade across borders, the *"first serious attempt"* to *"deepen integration and remove barriers"* was the Single European Act in 1987 (HBF 2018, 10). This was eight years before Austria joined the European Union. Electricity directives for improving competition and altering the national markets that were previously dominated by monopolies were adopted in 1996 and 2003. Thereby, a free choice of the electricity supplier was enabled. The next big step was the third energy package that established ENTSO-E. (HBF 2018, 10)

The **third energy package** was proposed by the EC in 2007 and entered into force two years later, in September 2009. This legislation package, which consists of three regulations and two directives, resolved structural problems and redefined the internal energy market. Five areas are covered by this package: first, the unbundling; second, the independent regulators; third, the Agency for the Cooperation of Energy Regulators, ACER; fourth, cooperation across borders; and fifth, the retail markets. Several regulations from this package were updated in 2019 by the following *Clean energy for all Europeans package* that contains new rules for the electricity market. (EC 2020c)

3.1.3 Cooperation Framework

To describe the relation between European objectives and the electricity network, it should be noted that to achieve its climate objectives, two areas are essential for Europe: first, system transformation costs need to be kept low through market integration efforts that lead to a competitive price for electricity and second, security of supply must be ensured for all Europeans. Both can only be reached through a pan-European approach regarding the planning of the future electricity system. (ENTSO-E 2019a, 3)

Currently, 42 transmission system operators are represented by the **European Network of Transmission System Operators for Electricity, ENTSO-E**. The scope goes beyond the European Union, as it represents TSOs from 35 European countries, including countries that are not members of the EU, as mentioned at the beginning of subchapter 3.1. (ENTSO-E n.d.e) According to Article 4 of the Regulation 714/2009 (EC 2009), the cooperation of all TSOs should happen through ENTSO-E with the aim to enhance both the functioning of the internal electricity market and cross-border electricity trade and *"to ensure the optimal management, coordinated operation and sound technical evolution of the European electricity transmission network."* Concerning consultations, Article 10 of the regulation mentioned above states that *ENTSO-E "shall conduct an extensive consultation process, at an early stage and in an open and transparent manner, involving all relevant market participants"* while preparing network codes, plans and programmes (EC 2009).

ENTSO-E is responsible for *"ensuring the secure and reliable operation of the increasingly complex network"*, *"facilitating cross-border network development and the integration of RES"* and *"enhancing the creation of the Internal Electricity Market, IEM"* (ENTSO-E n.d.d). Regulation 714/2009 outlines its tools and tasks in more detail and introduces the main planning instrument in Article 8, paragraph 3 (b) by stating that: *"a non-binding Community-wide ten-year network development plan, (Community-wide network development plan), including a European generation adequacy outlook"* should be adopted by ENTSO-E biennially (EC 2009). The TYNDP will be described in the following subchapter 3.1.4.

The main task of **transmission system operators, TSOs**, is to ensure supply security for their area of responsibility. In order to fulfil this task successfully, they must carefully analyse trends in the electricity system, such as the influencing factors that were described in subchapter 1.1, and consider in which manner and to what extend the grid must be developed for its future task. Therefore, TSOs conduct system adequacy assessments to evaluate whether their systems are prepared for the demand forecasts. Furthermore, TSOs run various calculations to constantly adapt their assumptions and be able to react within seconds, if there is an incident that endangers the grid and supply security. (ENTSO-E n.d.c)

The **Transmission System Operator Security Cooperation, TSC**, is one of the regional security coordinators in the context of ENTSO-E, which includes Austria and Switzerland (ENTSO-E n.d.c). It is a cooperation of 12 TSOs for enhancing the security of the system, since the problems that are arising due to renewable energies and the integrated market require better coordination for solving them. The aim is to achieve better forecasts for grid loads through cooperation. (APG 2013, 51-52) Regional security coordinators provide services, such as conducting calculations and making recommendations, to TSOs. However, TSOs are not obliged to follow these recommendations. (ENTSO-E n.d.c)

3.1.4 Planning Instruments

The purpose of the **Ten-Year Network Development Plan, TYNDP**, is to propose a project portfolio that contributes towards reaching European climate targets and improves the socio-economic welfare in Europe in general. It is a complex, but flexible plan. The scope of considerations that is included as a basis of this plan is unprecedented: extensive data was analysed, and thousands of system configurations were modelled depending on different generation and demand scenarios, different grid configurations, and different climate conditions. The TYNDP as a planning instrument is designed to adapt not only to shifting policy landscapes but also to macroeconomic trends and evolutions in the technological realm. (ENTSO-E 2019a, 6) This chapter considers the latest TYNDP 2018. The subsequent TYNDP 2020 package is currently in preparation and its publication is planned for March 2021 (ENTSO-E n.d.a).

To identify where investments into the electricity system are appropriate, first a system needs analysis is conducted, then the performance of not only transmission but also storage projects is analysed considering different scenarios (ENTSO-E 2019a, 6). All projects are assessed according to the **pan-European CBA methodology**, a cost benefit analysis that considers fifteen indicators. They are divided into three categories: eight benefit indicators, such as socio-economic welfare or RES integration; two purely economic cost indicators; and three residual impact indicators. One of these residual impact indicators is the environmental impact. (ENTSO-E 2019a, 8)

Furthermore, after the assessment, the TYNDP identifies key projects that are referred to as **projects of common interest, PCIs**, and enjoy a special status in the TYNDP project selection. The aim of the special status is to accelerate the planning and permitting process through favourable treatment. (ENTSO-E 2019a, 7) However, there is no causal relationship between the designation as a PCI and a favourable treatment since planning and permitting procedures are conducted on national level.

It should be noted that the **scenarios of the TYNDP** that are used as a basis for drawing conclusions differ strongly. Predictions about the future import and export flows between countries are uncertain and can impossibly be known with certainty. However, the TYNDP aims to identify *"projects that will be robust for a range of scenarios"* to help policy makers with decision-making concerning the building of new power lines (ENTSO-E 2019a, 3). The current TYNDP 2018 includes three long-term scenarios and considers a fourth external scenario. First, the *Sustainable Transition* (ST) scenario in which EU's 2030 is achieved while the 2050 target is not. Second, the *Distributed Generation* (DG) scenario that refers to a decentralised development and particularly considers end user technologies. Third, the *Global Climate Action* scenario is the most ambitious one, in which both the 2030 and 2050 emission targets of the European Union are reached through global decarbonisation in full speed and implementation of renewables on a large scale. *EUCO 2030* is the external scenario from the European Commission that is additionally considered. (ENTSO-E 2019d, 8)

There are four regional groups related to **priority corridors** in the context of the TYNDP. Both Austria and Switzerland are part of the North South West corridor, and Austria is also part of the North South East corridor. The remaining two are the Baltic States and the North Sea corridors. What all scenario results for 2030 have in common concerning the NSI West Corridor is that they all include the following two trends that affect both Austria and Switzerland: *"a reduction in nuclear generation capacity"* and *"an increase in hydro and pumped storage capacity"* (ENTSO-E 2019e, 10).

Overall, for the **NSI West Corridor**, the TYNDP 2018 scenarios show that the corridor in its entirety can be a net importer (EUCO), a slight exporter (ST) or almost neutral (DG). Austria is considered either a net importer in two scenarios (ST, DG), or an exporter (EUCO). However, for some countries, all scenarios give a clear answer to the question whether they are likely to be net importers or net exporters in the future: both France and Spain are exporters in all scenarios, while Italy is an importer in all scenarios. (ENTSO-E 2019e, 11)

Concerning the **NSI East Corridor**, the region's increase concerning its total installed capacity is regarded as the key driver in the context of grid expansion. For this corridor, the development of Germany and Poland is of main importance. Germany is likely to become an electricity exporter by 2030. However, if the implementation or renewable energy systems happens less rapidly, it will be a net importer. Poland is expected to become a large importer in two scenarios and a net exporter in the DG scenario. (ENTSO-E 2019d, 9-10) Compared to the NSI West Corridor, for the NSI East Corridor, the main developments are uncertain.

The focus of the grid development analysis for 2030 that addresses the future needs of system is on ***main boundaries***. Ten major boundaries that are closely related to natural barriers have been identified. Concerning Switzerland and Austria, the *Italian peninsula integration* affects both countries, while the *South-East integration* affects only Austria. (ENTSO-E 2019a, 24) All projects related to these main boundaries "contribute to achieving the interconnection target levels" discussed in 3.1.1 (ENTSO-E 2019d, 6).

Concerning the **South-East integration**, according to ENTSO-E's regional report, the driver for capacity increases on this main boundary is the integration of RES into a network that is relatively sparse. However, the price differences that are considered on this main boundary according to the CBA method "are not so high in comparison with other boundaries, so the capacity on this boundary in the 2030 scenarios could be considered as sufficient" (ENTSO-E 2019d, 25). Three projects are currently considered on this boundary but none of them is directly related to Austria. Regarding the **Italian Peninsula integration** that refers to connecting the Italian system to the European market, several projects that contribute to enhancing the capacity of this boundary relate to Austria and Switzerland (ENTSO-E 2019e, 25-29).

In the following two thesis chapters that cover national grid development strategies, these projects will be discussed from a national perspective. Prior to that, the following **Table 2** provides an overview of current power line projects related to Austria and Switzerland in the context of the priority corridors and main boundaries that were discussed in this subchapter. Only projects of common interest from the fourth and latest PCI list of the European Commission are considered (EC 2019). Since 2013, the EC updates the list every two years. The latest version was published in October 2019 and contains 149 projects in total. Two thirds of the projects relate to electricity storage and transmission (EC n.d.).

Table 2 – Projects of Common Interest

Priority Corridor	Countries Concerned	PCI Number	Project Number	Project Description & Status
NSI East	AT, DE	3.1.1	313	Interconnection between St. Peter (AT) and Isar (DE) *Project status:* in permitting
NSI East	AT	3.1.2	312	Internal line between St. Peter and Tauern (AT) *Project status:* in permitting
NSI East	AT	3.1.4	47	Internal line between Westtirol and Zell-Ziller (AT) *Project status:* under consideration
NSI East	AT, IT	3.4	210	Interconnection between Wurmlach (AT) and Somplago (IT) *Main boundary:* Italian Peninsula Integration *Project status:* in permitting
NSI West	CH, IT	2.14	174	"Greenconnector": Interconnection between Thusis/Sils (CH) and Verderio Inferiore (IT) *Main boundary:* Italian Peninsula Integration *Project status:* in permitting

(EC 2019, 2020b)

3.2 Austrian Strategy

This chapter will cover Austrian objectives in the context of the energy transition and how they relate to the necessary grid development. Moreover, it will analyse how the objectives and targets are reflected in the legal framework, the responsibilities of the planning process participants and in the planning instruments themselves.

3.2.1 Role of the Austrian Transmission Grid

Generally, Austria has large hydropower resources and they prevail in electricity generation. Variable renewable energy sources such as wind power plants are mainly located in the East, while pumped storage plants are in the Western part of the country. Decoupling Austria's energy consumption from population growth and the gross domestic product, i.e., economic growth, has not yet been successful. For achieving the 2030 energy consumption target, more efforts are needed and measures need to be extended. (IEA 2020a, 9) Since 2014, energy consumption has been increasing in both the transport and the industry sector but fluctuating regarding the residential sector (IEA 2020a, 17). Concerning the primary energy supply, in 2018, 29% were covered by renewables. Regarding electricity generation, 77% are attributed to renewable energy systems: 60% is assigned to hydropower and 17% to other renewables. In general, Austria plays a leading role in renewable energy. (IEA 2020a, 10) Referring to the grid development influencing factors that were discussed in the introduction, concerning variable renewables, from 2008 until 2018, the share of wind and solar energy increased from below 1% to almost 3% of total primary energy supply (IEA 2020a, 17). If we look at the electricity consumption in Austria, in 2018, it has reached a record high with 65.5 TWh. In 2030, 80-85 TWh and in 2050, 108 TWh are expected according to the Federal Ministry for Sustainability and Tourism (FMST 2018).

Austria shares borders with eight European countries and has existing electricity interconnections to seven **neighbouring countries** – all except the Slovak Republic (IEA 2020a, 32). Regarding the interconnection targets, in 2017, Austria's interconnection level to its neighbours was already 50% higher than the 2020 target of 10% (IEA 2020a, 43). There are two certified TSOs in Austria. 95% of the national transmission network concern the Austrian Power Grid, while *Vorarlberger*

Übertragungsnetz GmbH (VUEN) is responsible for Vorarlberg's transmission network, i.e., the province of Vorarlberg has an own TSO. However, there is only one control area that is managed by APG. (IEA 2020a, 36-37) Consequently, the Austrian Power Grid AG, is responsible for Austria’s national power grid and operates the trans-regional power transport network. Moreover, it manages the electricity exchange with neighbouring countries and is responsible for constantly maintaining the supply-demand balance. (APG n.d.a)

The Austrian **electricity market** liberalisation took place according to the EU framework. Since 2001, Austria was part of a zone of unified electricity-pricing with Germany that was valid for an unlimited transfer capacity (IEA 2020a, 35). This changed with the splitting of the price zone in the second half of 2018 which lead to a limitation of the interconnection capacity that is available for bilateral trade to 4 900 MW. This measure has led to a less competitive market. (IEA 2020a, 43) Concerning the future electricity market, pumped storage plants in Austria will gain importance on national and European level, since they contribute to a successful integration of variable renewable electricity generation by providing storage (IEA 2020a, 10).

Regarding electricity **imports and exports**, in 2018, cross-border electricity trade resulted in 8.9 TWh net imports for Austria: 28.1 TWh were imported and 19.1 TWh were exported. Imports were mainly coming from the Chez Republic and Germany, while electricity was mainly exported to Germany, Switzerland, and Slovenia. The development of electricity trade generally shows an increasing trend. (IEA 2020a, 31-32) As an electricity net importer, Austria aims to reduce the dependence on imports and, in the future, cover its total national electricity demand from domestic sources (IEA 2020a, 43). However, imports are currently expected to rise due to further increases in renewable energy systems (Freudenthaler et al. 2019).

Concerning the electricity sector, the Austrian government considers the annual APG network development plan as a preventive plan. Several high-voltage transmission lines that are included therein are crucial for the resilience of the Austrian electricity system, the achievement of climate and energy objectives, and the further integration of electricity markets in Europe. (IEA 2020a, 23) Concerning the necessary grid development in Austria, calculations showed that power lines in the vicinity of pumped storage plants and cross-border lines are expected to experience a significant increase in both medium and high load. Reasons for that are the central location of Austria in the European electricity network and the possibility that pumped storage plants offer in balancing variable renewable energy. (Umweltbundesamt 2011, 19) It should be noted that failures in accelerating the electricity infrastructure expansion "can become a major impediment for the decarbonisation of the energy sector by 2040" (IEA 2020a, 12).

3.2.2 Objectives

Austria's objective is to achieve **carbon neutrality by 2040**. Compared to the goal of the European Union, it is very ambitious as it is ten years earlier. The current national approach regarding the energy sector is stated in the *Austrian Climate and Energy Strategy 2030 #mission2030* that was launched in 2018 (IEA 2020a, 18-19). Although successful efforts were made in the past, achieving carbon neutrality still requires "building on and expanding existing policies and measures" and, concerning all energy sectors, a substantial enhancement of decarbonisation efforts (IEA 2020a, 9). In that sense, accelerating the electricity infrastructure expansion is one of the required measures for decarbonising the energy sector by 2040 and a failure to do so could significantly impede the process (IEA 2020a, 12).

Moreover, Austria's objective is to achieve a **fully decarbonised electricity sector by 2030**. This will help in reaching the previously described carbon neutrality goal by 2040 and substantially increase the role of electricity in the energy mix, which is crucial for an energy system electrification that is sustainable. In more detail, the 100% renewable electricity supply, i.e., fully decarbonised electricity sector target, is defined as the total generation including electricity exports but excluding electricity imports. There are two exceptions since it does not include "generation required for balancing and control of the grid" nor "self-consumption of electricity from industrial by-products" (IEA 2020a, 10). To reach the 100% renewable electricity (national balance) objective it is necessary to invest in generation capacity, repower older wind turbines and deploy "additional grid infrastructure" (IEA 2020a, 30). Concerning electricity not only the "100% renewable electricity consumption (national balance)" is a 2030 target but also, as mentioned before, the elimination of the dependency on electricity imports (IEA 2020a, 19).

To reach climate and energy objectives, large sums need to be invested into the power grid. In line with the awareness of the importance of grid modernization, according to APG’s Network Development Plan, **investment volume** reaches almost three billion euros for the upcoming ten years, i.e., the period between 2020 and 2030. These investments into the grid are considered to be an economic stimulus, since studies imply that 70% of the amount will remain within the country and, inter alia, create jobs in Austria. (APG n.d.c) Generally, in the Continental Central East region related to the NSI East priority corridor, the further grid development and grid investments should reflect the main trends in the region: the cross-border electricity flows have significantly increased in the north-south direction, while they have decreased in the opposite direction. The physical flows are changing mainly due to the changes in the electricity generation mix in the region. (ENTSO-E 2019b, 14) Furthermore, the Regional Investment Plan of the Continental Central South region, related to the NSI West priority corridor, highlights the need for investments into both the closing of the 380 kV ring in Austria to strengthen the internal transmission network and the interconnections to neighbouring countries. The need for reinforcement arises due to the interaction of wind farms and pumped storage plants. (ENTSO-E 2019c, 12) The mentioned 380 kV ring is part of Austria’s target grid and will be described in subchapter 3.2.4.

3.2.3 Legal Framework for Grid Development

Energy policy in Austria is a realm where the **federal and regional level**, the nine provinces, share their competences. Concerning, for example, the issues of infrastructure permissions, land use and zoning, the responsibility lies with the regional governments. However, if electricity infrastructure projects extend over at least two of the nine provinces, the competencies of the federal level apply. (IEA 2020a, 11) Austria’s climate and energy strategy *#mission2030* acknowledges the complexity and the long duration of the permitting process. One step towards reducing the complexity was done with the newly created combination of several crucial energy topics under the new ministry in January 2020. However, the shared competencies of the federal and regional governments remain an issue. (IEA 2020a, 11)

Concerning **permitting procedures**, the IEA also finds that *“the existing legal and administrative procedures are complex and time-consuming”* (IEA 2020a, 24). Regarding the challenging expansion of electricity infrastructure, the IEA claims that Austria needs to streamline approval procedures. Therefore, in 2014, an assessment of costs and benefits related to the current distribution of competences and, where appropriate, adjustments to both legal and regulatory frameworks were suggested by the IEA. (IEA 2020a, 11) In the meantime, several steps have been taken towards a simplification of the procedures. For instance, the *Energy Infrastructure Law* aimed to create a centralised permitting procedure at the federal level in 2016 with the purpose of reducing the administrative complexity. Moreover, a special law was passed in January 2019 to accelerate the permitting procedure for infrastructure projects that are “of special public interest” (IEA 2020a, 24) This law, *Standortentwicklungsgesetz* in German, on infrastructure projects, is highly controversial and has received critics from the EU which led to an infringement procedure since the EU finds that the EU directive regarding environmental impact assessment has been incorrectly transposed into the Austrian “Location Development Act” (IEA 2020a, 36).

According to APG, in addition to the complexity and duration of permitting procedures due to the allocation of competenci*es,* human resources on the side of the authorities and experts that are responsible for the of the proceedings can delay the procedures as well. In general, APG favours all improvements concerning the duration of proceeding and suggest, for instance, to harmonize thresholds relevant to permitting procedures and to protect existing and planned routes by restrictions concerning buildings underneath. These improvements in the federal framework conditions are required for a successful and sustainable energy transition. Furthermore, APG highlights the importance of public and political acceptance concerning the required grid development. (APG n.d.c)

3.2.4 Planning Instruments

In 2013, APG finalised its **Masterplan 2030**, a long-term planning tool about the transmission grid development in Austria for the period from 2013 to 2030. Additionally, an outlook regarding the electricity sector developments until 2050 is included in this plan. Based on future scenarios, it defines required grid development measures for the target grid of 2030 (APG 2013, 4).

To select relevant projects related to the **target grid**, three electricity scenarios were determined jointly by TU Graz, TU Wien and APG. Then, network loads were simulated according to these scenarios and specific cases to determine where congestions and bottlenecks are likely to occur. In the next step, key projects were determined and included in the plan. (APG 2013, 45) Generally, the APG target grid includes the completion of the 380 kV ring, a more efficient transport of electricity in the West of Austria, and stronger connections to the transmission networks of the neighbouring states (APG 2019, 40).

According to the Electricity Industry and Organization Act, *Elektrizitätswirtschafts- und -organisationsgesetz 2010*, a **network development plan, NDP,** is legally required and is to be prepared by the TSO. The NDP is based on the preceding plan of the previous year and the Ten-Year Network Development Plan of ENTSO-E. The purpose of the plan is to inform about transmission infrastructures that require further development. After the consultation period, during which relevant market participants can comment on the plan, APG considers these comments and then submits the plan to E-Control, whose approval is needed for the final publication of the plan. (APG n.d.c) Not only APG but also "Vorarlberger Übertragungsnetz GmbH" annually publishes a new NDP that needs to be approved by E-Control (FMST 2018, 35). In general, the TYNDP 2018 contains all NDP 2019 projects. However, due to different states of planning and different timescales, there are some deviations and discrepancies (APG 2019, 38).

Concerning the **grid projects** that are currently planned in Austria, the NDP 2019 includes about 230 km of new transmission lines, i.e., grid expansion, about 110 km conversion to a higher voltage level, and about 400 km general refurbishments of lines. Moreover, in the context of one of the large-scale line projects referred to as the "Salzburg line", about 65 km require dismantling. Concerning transformer stations, about 150 new or upgraded control panels are planned, and regarding couplings of grid levels, about 30 transformer stations with an overall performance of 11.000 MVA are required by 2029. (APG 2019, 11) APG finds that particularly the necessity of projects of supra-regional interest is often questioned regionally and refers to the creation of regional and general public acceptance as one of the biggest challenges for network expansion (APG 2019, 101).

Three APG projects are **projects of common interest** according to the European Commission and thus relevant for a sustainable European grid: the Germany line connecting St. Peter in Austria and Isar/Ottenhofen in Germany; the "Salzburg line" connecting St. Peter and Tauern in Austria; and another national power line connecting West Tyrol and Zell/Ziller (APG n.d.c). Furthermore, a fourth project that affects Austria can be found in the fourth list of PCIs as well: a merchant line between Wurmlach in Austria and Somplago in Italy with a total length of 51 km from which only 11 km are in

Austria. This project is not included in the NDP 2019 since it is not promoted by APG but by promoted by “Alpe Adria Energia”, an Italian company. (EC 2020)

The **Salzburg line** is required for closing the gap in the “Austrian 380 kV ring” (IEA 2020a, 40), a key concept for the security of supply in Austria. It is an internal line with a total length of 174 km that connects St. Peter in Upper Austria and Tauern in Salzburg. 46 km require a reinforcement to 380 kV, while 128 km count as grid expansion. It is a core project of APG since it is highly important for the security of supply on both national and regional level. Furthermore, it contributes to connecting the pumped storage plants in the southwest of the country to Austrian and European wind power locations. (APG 2019, 56-59) Concerning the transnational importance of the line, additional transport demand is generated in this area since electricity generation is increasingly being shifted to the north of Germany and south of Italy, where conditions for RES are optimal, instead of generating the required power close to the centres of demand (ENTSO-E n.d.f).

The interconnection **between Isar in Germany and St. Peter in Austria** is required for enabling greater cross-border transfer capacities (IEA 2020a, 40). This line is promoted by both APG and TenneT TSO GmbH, one of the German TSOs. (EC 2020) The project is essential due to the planned expansion of renewable energy systems in northern Germany and their interaction with Austrian pumped storage plants. Transmission capacities are already largely exhausted and internationally coordinated congestion management is essential is this area. It should be noted that only several kilometres of the line are required in Austria and the major part is located in Germany. (APG 2019, 51-52)

The transmission line from **West-Tyrol to Zell-Ziller** will be connected to the 380 kV ring (IEA 2020a, 40). The line is essential for a better integration of renewable energy systems and pumped storage plants into the market (APG 2019, 41). The project remains under consideration and is not in the permitting phase. It includes the upgrade of an existing 110 km line of 220 kV to extra-high voltage and the erection of additional transformer stations. (EC 2020) Thereby, it connects the 380 kV ring to the transformer station in western Tyrol, which is an important network node in western Austria since it is connected to the following transmission networks: first, the German transmission grid; second, the Swiss grid; and third, the power grid of Austria’s second TSO, VUEN, in Vorarlberg. Due to its location, this overhead line project is referred to as the “Inn Valley Axis”. (APG 2019, 78)

3.3 Swiss Strategy

This chapter will analyse Switzerland's objectives and circumstances in the context of its energy transition efforts. The role of the Swiss transmission network and the importance of its further development will be described. Additionally, the legal framework and possible improvements will be discussed. Finally, grid planning instruments and their priorities in the context of a sustainable European electricity grid will be described.

3.3.1 Role of the Swiss Transmission Grid

Switzerland, surrounded by EU member states, is facing a major transformation of its energy system, as in 2017, Swiss people decided to gradually phase out nuclear power. Although Switzerland still heavily relies on nuclear energy, it is commendable that, according to the IEA (2018, 11), it has managed to decouple its energy consumption from its economic and population growth. Regarding electricity generation, the Swiss government intends to implement more renewables in the future, but its current share is low: in 2018, renewable electricity generation accounted for 3877 GWh which equalled 6.1% of total electricity generation, with around 50% being solar power, while the share of wind energy is very low with only 3.1% (SFOE 2019b, 12). It should be noted that nuclear energy provides approximately 35% of the electricity generation. Since measures for increasing the share of renewable energies other than nuclear are not likely to suffice, increasing imports are also intended to compensate for the future lack of nuclear energy. (IEA 2018, 11-12)

The **electricity consumption** per capita decreased since 2000 and Switzerland's target concerning a 3% lower consumption per capita by 2020 was already achieved in 2016 (IEA 2018, 125). In general, due to a higher electricity demand for heating purposes and hydrological conditions that lead to a lower hydropower capacity, Switzerland's electricity consumption reaches a peak in winter (IEA 2018, 67).

Switzerland is well interconnected to all five of its **neighbouring countries** and thereby closely integrated in the European grid. Historically, "The first international interconnections in Europe came in 1906, when Switzerland built transmission links to France and Italy" (UN 2006, 15). Today, Switzerland has 41 cross-border interconnections (Axpo n.d.). Swissgrid, Switzerland's transmission system operator and a member of ENTSO-E, is responsible for the management of the national power grid. ElCom, the Federal Electricity Commission, is the Swiss independent regulatory authority that is responsible for the access to the grid and the conditions of its use. Furthermore, electricity trading and transmission across borders concern ElCom as well since it monitors the congestion management that is done by the TSO. (IEA 2018, 68)

The **electricity market** in Switzerland has only been partially liberalised. If the consumption exceeds 100.000 kWh, which is the case for below 1% of all end consumers and applies to around 32.500 companies, the electricity supplier can be chosen freely. Otherwise, consumers are not allowed to choose their electricity supplier. A full market liberalisation that enables competition and eliminates market distortions is envisaged, but not yet clarified in detail. Currently, there is no information about how and when full liberalisation should take place. Since it is a politically controversial topic, a referendum by which Swiss people will decide on this issue is likely. (Axpo n.d.) With regards to innovation benefits and a greater choice for consumers, the IEA (2018) review recommends fully opening the Swiss electricity market and fully integrating it into the European internal electricity market.

About 10% of electricity that is exchanged in Europe is transported through Switzerland, which is why Switzerland is often referred to as ***Europe's electricity hub***. Not only the central location, but also the fact that Swiss hydropower is available within seconds is responsible for the high amount of electricity trading through Switzerland. (Axpo n.d.) In 2017, Switzerland imported 36.4 TWh, while it exported 30.9 TWh of electricity, which results in net imports. Over the last decades, the country has developed from a net exporter of up to 10 TWh to a net importer in some years. (IEA 2018, 66) Generally, the electricity production is higher in summer than in winter, when the country becomes dependent on imports. According to Axpo, 2002/03 was the last winter in which the country did not need imports to cover its electricity demand. (Axpo n.d.) Concerning import dependency, in Switzerland, there is a debate "on whether Switzerland should be self-sufficient in electricity throughout the year, including during the cold winter period when it relies on imports from the rest of Europe" (IEA 2018, 11).

Concerning the **relation to the EU**, on the one hand, Switzerland benefits from the EU through its role as a European electricity hub, due to its central position and the large number of interconnections. Since electricity trade is expected to be further intensified in the future, the connection to the European internal market for electricity is a precondition for maintaining these benefits. (Swissgrid n.d.d) On the other hand, the EU benefits from Switzerland's storage lakes that are valuable for both the national supply security and ensuring the stability of the neighbouring countries' grids (Swissgrid 2015b, 15). To improve cross-border electricity exchange and thereby enhance supply security, clear regulations regarding Switzerland's participation in the electricity market of the EU are required (Swissgrid n.d.d). Negotiations for an electricity agreement between Switzerland and the European Union started in 2007 (IEA 2018, 15). A successful outcome of these negotiations is supported by the IEA and although the conditions for the agreement are not completely negotiated, Swissgrid acknowledges that in the future "there will only be one common internal electricity market for all of Europe" (Swissgrid n.d.d).

Since **cross-border electricity exchange** is essential for increasing Switzerland's supply security as it allows for importing electricity when domestic production is low, and grid overloading due to the expected increase in electricity exchange is to be avoided, the expansion of the domestic grid becomes necessary (Swissgrid 2015b, 16).

3.3.2 Objectives

Switzerland's ***Energy Strategy 2050****,* ES 2050, sets targets for both overall energy, related to the share of renewables and energy efficiency, and electricity consumption by 2035. However, these targets are non-binding. (IEA/IRENA 2018) The Strategy is guided by Switzerland's long-term climate goal which is to, by 2050, reduce its carbon dioxide emissions to 1.0-1.5 tonnes per capita (IEA 2018, 12). According to Axpo, the largest Swiss producer owned by the public sector, the ES 2050 is "too optimistic in terms of production prognoses, consumption estimates and the assumptions concerning the possible import of power from abroad" and a "realistic review" of the strategy "is absolutely essential" (Axpo n.d.). Similarly, according to SFOE's second monitoring report regarding the Energy Strategy 2050, in the long-term, additional efforts and measures are required for a successful energy transition in Switzerland and the achievement of its targets concerning renewable energies and energy efficiency (SFOE 2019b). Additionally, with regards to the electricity market, for a successful implementation of the Energy Strategy 2050, the integration into the European power market, as discussed before, is of major importance (Swissgrid n.d.d).

According to the strategic plan of Swissgrid, an **investment volume** of 2.46 billion Swiss francs was expected to be invested in the Swiss grid in the period between 2015 and 2025. The peak of investments, on an annual basis, was assumed to be in the first two years. (Swissgrid 2015a, 206-210) According to ENTSO-E's Regional Investment Plan 2017, "the actual planned grid for Switzerland presents some overloads due to the higher and more volatile power flows across Europe" and therefore requires "enforcements of the cross-border and internal power lines" particularly in the context of its north-south axis (ENTSO-E 2019c, 34). One of the **key investments** is an upgrade of the Bassecourt-Mühleberg power line to 380 kV due to the planned shutdown of the nuclear power plant in Mühleberg, which is likely to cause higher imports in compensation. Furthermore, grid investments are required to maintain the network security and manage tight network spots that occur at cross-border interconnections with Germany. (IEA 2018, 71-73)

3.3.3 Legal Framework for Grid Development

Regarding **federal and cantonal competencies**, the responsibility for energy issues that are of national importance for Switzerland lies with the federal state and the ministry in charge is the *Department of the Environment, Transport, Energy and Communications*, DETEC. Within the ministry, the practical management of energy-related issues is done by the *Swiss Federal Office of Energy*, SFOE. However, cantons have a certain leeway and their policies are crucial for energy infrastructure concerning zoning and permitting procedures. (IEA 2018, 23-24)

The general legal basis for grid access, grid management and the national electricity grid company is specified in the **Electricity Supply Act**. Moreover, the grid regulator's responsibilities are included in this law. (IEA/IRENA 2017) Concerning the national strategic approach, the Swiss Parliament adopted a revised **Federal Energy Act**, which established the ES 2050 discussed in the previous subchapter, in September 2016, which superseded the previous act from 1999. After the referendum in May 2017, that also confirmed the nuclear phase out, it entered into force at the beginning of 2018. The aim of this revised Federal Energy Act is "to ensure an economically and environmentally viable supply and distribution of energy, thrifty and efficient energy consumption and a transition towards renewable energy supply, particularly from local sources" (IEA/IRENA 2018).

The SFOE recognizes the need for action concerning the further development of the grid and an improved congestion management. However, there is only slow progress in this area due to conflicts of interest, insufficient transparency of the proccesses, a lack of understanding of the need for further development and a lack of public acceptance (SFOE 2018, 22).

3.3.4 Planning Instruments

The **Strategic Grid 2025** is Swissgrid's long-term plan that provides a detailed and transparent insight into the required grid development measures until 2025 in Switzerland (Swissgrid 2015a, 15).

It includes nine **grid development projects** on the **national level**. In more detail, related to the NOVA categories discussed in chapter two, these projects account for 193 km grid optimisation measures, 87 km grid reinforcement measures and 245 km grid expansion measures, i.e. new power lines. In addition, 125 km of grid expansion in the context of the distribution grid is planned, which is not included in the nine projects. Overall, grid expansion of 370 km, including both the transmission and distribution grid, and grid dismantling of 270 km concerning the transmission grid and 145 km related to the distribution grid, result in a decrease in power line route length, since the dismantling compensates for the expansion. (Swissgrid 2015a, 17-18)

On European level, three projects of relevance for the European grid were considered in 2015, when the Strategic Grid 2025 plan was published (Swissgrid 2015a, 197). However, the circumstances have changed and currently, only one project remains in the latest PCI list of the EU. Moreover, it should be noted that Swissgrid examined and evaluated the **three projects of common interest** concerning the European electricity grid even though they were not included as part of the final "Strategic Grid 2025". (Swissgrid 2015b, 18) At the time of the publication of the strategic plan, the following three PCIs related to Switzerland were considered: first, Mettlen-Verderio, also referred to as the "Greenconnector" which is the project that is still under consideration; second, a power line related to San Giacomo; and third, the Lake Constance interconnector. The first one was technically not necessary considering capacities in Switzerland and Italy in 2015, but *"depending on the development of the projects planned in Europe, and in the case of a politically desired increase in capacities to Italy"* the project would technically make sense (Swissgrid 2015b, 18). The second project, San Giacomo, has been partly realised. However, regarding the necessity of the project, it was similar to the first mentioned project Mettlen-Verderio, since it was considered technically not necessary and was related to political considerations about increasing the capacity to Italy. The third project, Lake Constance interconnector, is a new extra-high voltage line to Austria and Germany and would lead to a capacity increase the in the Northern Alps and, again, is of relevance for electricity transmission to Italy. In this context, Swissgrid assumed that the development concerning imports and exports on Switzerland's northern border up to 2025 will not require higher voltage lines. (Swissgrid 2015b, 18)

Generally, Switzerland is important for **linking Italy**, that is import-dependent, with the electricity market in the North (Schlecht and Weigt 2015), which is reconfirmed by the former and current choice of PCIs in that region, although the Lake Constance transmission line was removed from the PCI list. However, concerning the PCIs, the Strategic Grid 2025 finds that although a certain net transfer capacity increase was assumed to be needed according to ENTSO-E and the concept of the PCIs aims to accelerate the implementation of the chosen grid development projects, the conflicting interests of the involved parties and complex rules on financing are likely to delay the possible implementation of the projects (Swissgrid 2015a, 63).

The project that is included in both the Strategic Grid 2025 and the fourth PCI list is the **"Greenconnector"**. This transmission line is only relevant to Swissgrid in its "On Track" scenario, while in the "Slow Progress" scenario that assumes a belated transposition of the implementaiton of renewables, the project "Castasegna-Mese" is considered to be sufficient and the Greenconnector is likely to be less relevant (Swissgrid 2015a, 63).

In more detail, the Greenconnector is not an overhead line, but a **HVDC cable** interconnector from Verderio Inferiore in Italy, near Milano, to Thusis in Canton Graubünden in Switzerland. 45 km of the line, which is about one fourth of the total length, are located in Switzerland, while 120 km are on the Italian side of the border. About 50 km are planned under the Como lake as an undersea cable. Moreover, an old existing oil pipeline that has not been in service since 1997 will be used for a part of the route. (EC 2020b)

According to ENTSO-E (n.d.b), the additional capacity of this underground and undersea cable will significantly contribute to reaching the Italian interconnection target of 15% by 2030. Concerning technical and environmental aspects, the part of the line that will use the existing pipeline route has a limited environmental impact due to the reduced amount of civil works that are required and the interconnector is generally considered to be very efficient and have very low losses as a result of to the technology that has been selected. However, due to local opposition, a new location for the converter station in Switzerland is evaluated. Furthermore, rerouting the final part of the line is under consideration. (ENTSO-E n.d.b)

From a Swiss perspective, the project was evaluated negatively. As mentioned before, it is technically necessary only in the "On Track" scenario. Concerning macroeconomic considerations, the Swiss economy is negatively affected by the project. Due to higher capacities to Italy, electricity prices in Switzerland would adjust to Italian prices which would have a negative effect on Swiss consumers, while Italian consumers would benefit from a lower electricity price. (Swissgrid 2015a, 180-182).

3.4 Comparative Overview

Table 3 – Comparative Overview

	Austria	**Switzerland**
General Features		
TSOs	APG VUEN	Swissgrid
Grid investment estimations	time period 2020-2030: € 2.9 billion (APG n.d.c)	time period 2015-2025: 2.46 billion CHF (Swissgrid 2015a, 206)
Environmental Considerations		
Magnetic field limits	no legally binding limits	1 μT installation limit
Noise limits	no legally binding limits	in residential areas: 55 dB at day 45 dB at night
Transnational Considerations		
European priority corridors (ENTSO-E)	NSI West NSI East	NSI West
Main boundaries (ENTSO-E)	Italian Peninsula Integration South-East Integration	Italian Peninsula Integration
PCIs from the fourth PCI list (EC 2019)	4 PCIs in total: 2 internal power lines; 2 cross-border power lines: 1 to Germany and 1 to Italy	1 cross-border underground cable to Italy

4 Conclusion

The past decade has seen main structural changes regarding the planning framework of the electricity transmission infrastructure across Europe. The purpose of this thesis was to outline the current framework conditions for planning a sustainable and well-interconnected European transmission grid, and their implications for Austria's and Switzerland's grid planning approaches. By analysing the interdependencies of common European approaches towards the development of a sustainable transmission network of the future and the national strategies of Austria and Switzerland, this thesis has shown that mutual benefits prevail and a further transmission grid development can only be sustainable if cooperation efforts are successful.

Returning to the main research question posed at the beginning of this thesis, it is now possible to state that, concerning the role of the Austrian transmission grid in the European context, the currently planned power line projects in Austria are technically necessary for improving the security of supply, the integration of renewable energy systems and better connections to pumped storage plants. In contrast to that, the relevance and necessity of the Swiss projects of common interest is rather dependent on political decisions, not physical considerations, and the fact that Swiss PCIs were not included in its strategic grid plan for 2025 implies that the cooperation is improvable in this regard. The current lack of technical necessity refers only to the Swiss PCIs and only from the Swiss perspective, not to the entirety of Swiss grid development projects.

The Swiss electricity transmission infrastructure is already playing a significant role in the continental electricity grid due to its geographical position and high level of interconnectedness. However, in the future, the Swiss network and its interconnections will gain importance for the country's own security of supply. This follows from both the planned partial compensation of nuclear electricity through imports and the planned integration into the European internal electricity market accompanied by legislative changes. Consequently, further development of the Swiss grid is essential for a successful implementation of both plans, the transition to a non-nuclear electricity supply, and the full integration into the European electricity market. It remains to be seen, to what extent the bilateral negotiation outcome between the EU and Switzerland will affect the role of the Swiss transmission grid.

With regard to increasing electricity demand, a relatively higher share of renewables in the energy mix and more frequent and more intense congestions, i.e., the three influencing factors that were outlined in the introduction and are mainly responsible for the necessity of further grid development, it was found that, although generally relevant for all Europeans, these factors do not affect both countries in the same way. On the one hand, Switzerland has decoupled energy consumption from economic and population growth, while Austria has not. On the other hand, the relative share of variable electricity sources is noticeably higher in Austria than Switzerland. However, Switzerland's transmission grid is likely to be similarly affected by increasing renewable energy shares due to its high interconnectivity level.

In conclusion, by applying high technical and environmental standards in the context of its grid development projects and by supporting cross-border cooperation that aims to solve transnational challenges to the best possible extent, while ensuring reliability and security of supply, both Austria and Switzerland contribute towards enabling a sustainable future grid in Europe.

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List of tables