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INTERNATIONAL ELECTRICITY EXCHANGE IN CENTRAL AND WESTERN EUROPE: PROBLEMS AND CHALLENGES

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1 Abstract

The electricity exchange in Central and Western Europe has changed tremendously in the past 3 decades. There are several reasons for this.

First reason is, that new energy sources need to (and have been) be incorporated into the grid. Sources like solar and wind, intermittent in their nature, are challenging to use on a large scale. With them, new ways of grid-management need to be utilised. Management that allows better integration among countries and faster response. Otherwise everyone could (and some have) feel the negative effects of large scale implementation of intermittent sources.

Second reason is market liberalisation that has begun in 1990s and has continued since then. Even now-days is not the market, in several countries, fully liberalised.

Before the intermittent sources integration existed mostly pure producers of electricity and pure consumers. That has changed since then. Now-days even the consumers can be producers. That is mostly due to implementation of renewables like photovoltaics. This situation makes it rather difficult for the grid operators. It's become increasingly hard precisely predict the demand/production. It's not ”men” dependent, as it used to be anymore, but rather weather dependent. The inability to predict the weather precisely, not enough grid-scale level power storage to balance the power out leads to dangerous ”occurrences” in the grid. These ”occurrences”, can overload certain transmission lines, bottlenecks in the grid are more visible and set frequency can be altered to undesirable levels. Furthermore this kind of use of inherently unstable grid can then lead to blackouts.

2 Europe

2.1 Regulators and System Operators

Central and western Europe are directly interconnected. That means each possible power plant blackout can cause frequency decreasing in each connected country. So the volatile feed-in from the renewable energy resources like photo-voltaic and wind power are affecting the frequency all over Europe. Therefore it is mandatory to regulate the energy consumption and production across the country's border. The organisation which is responsible for this is called Entso-e [6]. In Picture 1 you see all the members of this organisation with their shortcut.

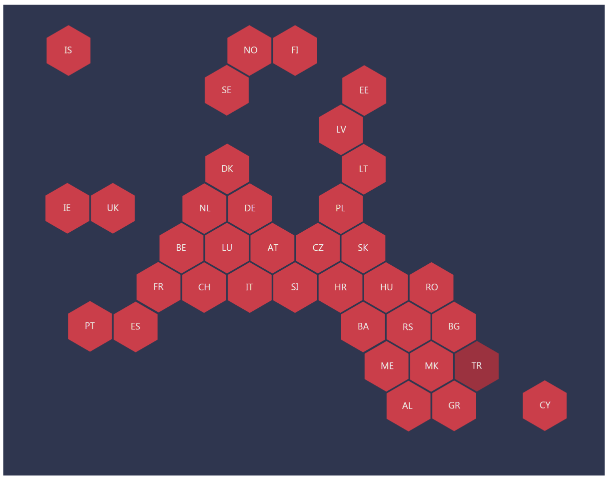

Figure 1: Members of the Entso-E

This association is constituted of all transmission operators (TSO) in Europe. In Austria this association is called Austrian Power Grid (APG) [2] and Vorarlberger Übertragungsnetz GmbH (VUEN) and in Czech Republic it is ČEPS. Each of this association is managing the power flow in their own control zone to keep the frequency at 50 Hz. These companies are also coordinating the grid development, controlling the energy access from power plants and consumers and the security of power supply. Regularity guard-lines are called technical organisation rights (TOR) or, the new version from ENTSO-E, Network Codes. These Network Codes are valid for all TSO's in Europe and take effect as a EU-regulation. Furthermore this code is regulating three main areas. These are connection, system operation and market [2]. Which are further divided into specific regulations see 2.

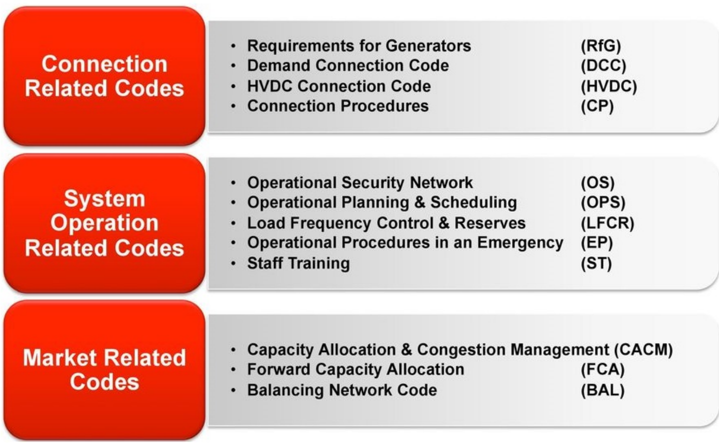

Figure 2: Network codes with specific regulations

3 European Union

The European Union (EU) has strong interests to keep the grid system stable by decreasing CO_2 emissions. A stable and well working power grid is a must have for a flourishing economy. Therefore the European Union has founded the ENTSO-E (European Network of Transmission System Operators for Electricity). One main purpose of this organisation is the support of projects which improves the stability of the grid system or are useful to guarantee a liberal and free access to the energy market. Each project has to be submitted to the ENTSO-E and is going to be considered by experts at ENTSO-E and EU. After a favourable decision the project gets the status of a PCI which means a project of common interests. In that case the project is getting supported with money from the European Union.
How much and how long depends on the priority of the project. Furthermore the ENTSO-E is active in Research and Development and has now published their third RDI Roadmap 2017-2026. That is the groundwork of the European Commission's Roadmap 2050. This road map gives the main parts for upcoming electricity highways, smart grids and for the change to a low-carbon electricity system. The pulled points are [7]:

- Power System Modernisation
- Security and System Stability
- Power System Flexibility
- Power System Economics Efficiency
- ICT Digitalisation of Power System

Another big challenge for European Union is to find laws and regulations which are applicable for all countries in Europe. These so called network codes need to be harmonised with the TOR. They should be also quit precisely and support all members which are part of the energy system. At least it is necessary to have lean structures for an easy access to the energy market.

A big challenge for the EU is to achieve the climate targets. The 20-20-20 goals are a program, from the EU. This was set to reduce 20 % of the greenhouse gases from 1990 until 2020. Also increase 20 % of the renewable energies and increases the energy efficiency to 20 % [5]. The idea of this program is to solve our energy challenges. It is absolutely necessary that each country is reaching this targets. Another way are the projects of common interests as already mentioned.

3.1 Challenges

Problem with European TS (transmission grid) and DS (distribution grid) is that they were build in the era of centralised power generation and low amount of power sources. This is due to the early development of TS and DS in Europe. Current developing countries have a distinct advantage in this aspect. Their infrastructure is yet to be build. When we have a look at Germany in the region operated by 50 Hz for example. In 2020 there were in 30.000 units or solar, biomass and wind combined. In the year 2020 the total amount is on track to 2.700.000 units. That's jump of 2 orders of magnitude. Today in the 50 Hz grid the renewables cover over 50 % of installed capacity. [14]

3.1.1 Base load power plants misconception and deeper implementation of intermittent renewables

As we can see in the pictures 3 and 4, Germany has implemented so many renewables that it at certain times leads to few years ago almost "unheard off" things.

In these pictures is visible that deeper implementation of renewables, preferential access to grid of renewables and certain weather conditions can lead to hugely uneconomic regulation of nuclear power generation. Prices of electricity of course correspond with this phenomena. There is a common misconception about intermittent renewables and base load power plants. That is that renewables can't provide base load power and that we need traditional steam and nuclear to do that instead. Problem is that with deep enough implementation of renewables there is no space for hard to regulate classical poweplants. Hence they can't be economically regulated and therefore are unable to respond to all the time changing generation of renewables with preferential access to the grid. This corresponds with Germany's closing of nuclear power plants. That is not only political but in the consequence of the Energiewende also necesarry from the technical point of view. Otherwise wouldn't be deep implementation of renewables possible.

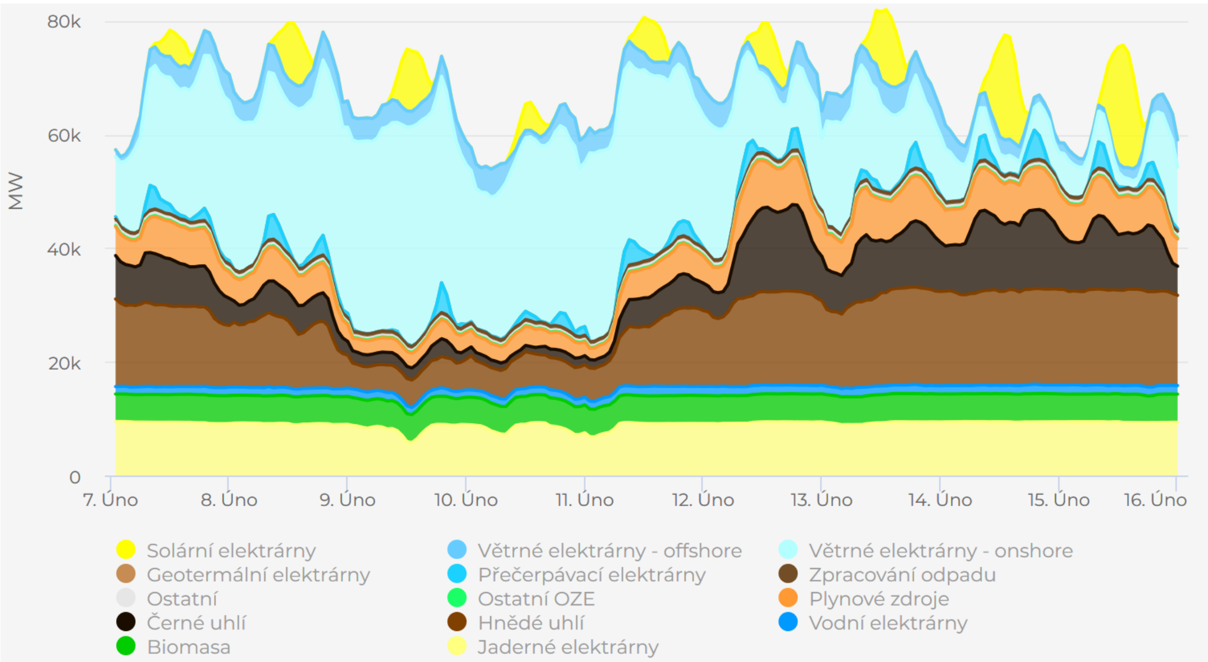

Figure 3: Electricity production in Germany between 7.2. and 16.2. 2019. Bottom yellow stands for nuclear, light blue for wind and darker yellow for solar. [11]

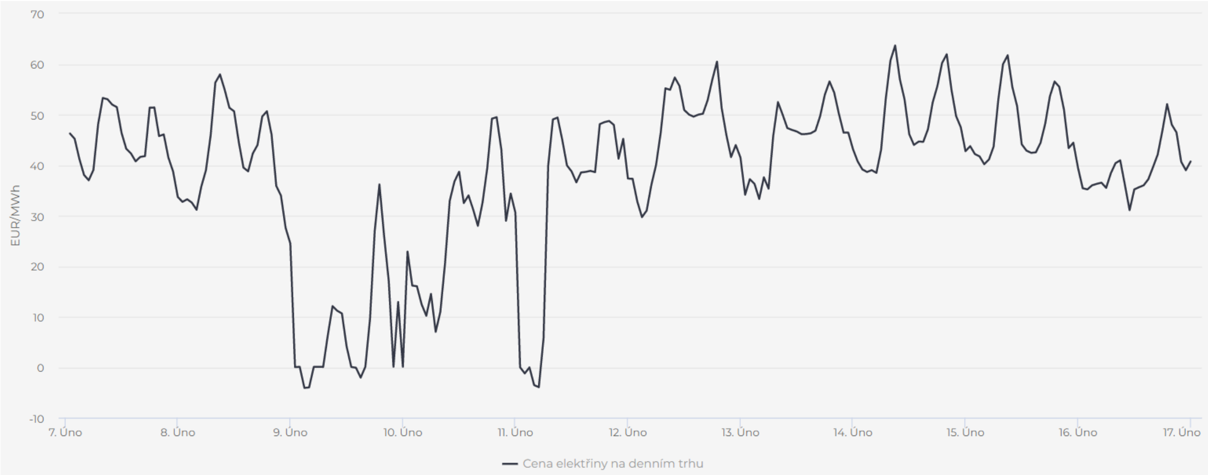

Figure 4: Electricity prices in Germany between 7.2. and 16.2. 2019. [11]

3.1.2 Scope of things

To better understand the scope or things. ENTSO-E incorporate 5 different synchronous (AC connected) grid areas (so called regional groups). These areas are: Continental Europe, Scandinavia, United Kingdom, Ireland and Baltic countries. There are 35 interconnected countries (42 TSOs). As seen in the figure 1.

1. Installed capacity: 1.030 GW
2. Consumption: 3.278 TWh/a
3. Peak load: 528 GW
4. Physical exchange: 400 TWh/a
5. Population: 532 millions
6. 305.000 km of transmission lines
7. 104 Billion euros in ten year investment plan

[14]

These figures demonstrate enormity of the system and the huge consequences that could occur if something went wrong.

3.2 Projects

3.2.1 Connected europe

As touched in the chapters above, most of the problems have the same common denominator. This is implementation of renewables into the European grid. Higher the implementation the harder it is to contain the negative effect on the grid. That translates into negative effects to consumers, national economies, energy security etc.

To combat these effects, there are several strategies. One of most promising strategy is to build more robust and more connected network, that reflects needs of many distributed sources of energy and implement additional grid stability features like storage and more easily controlled conventional power plants.

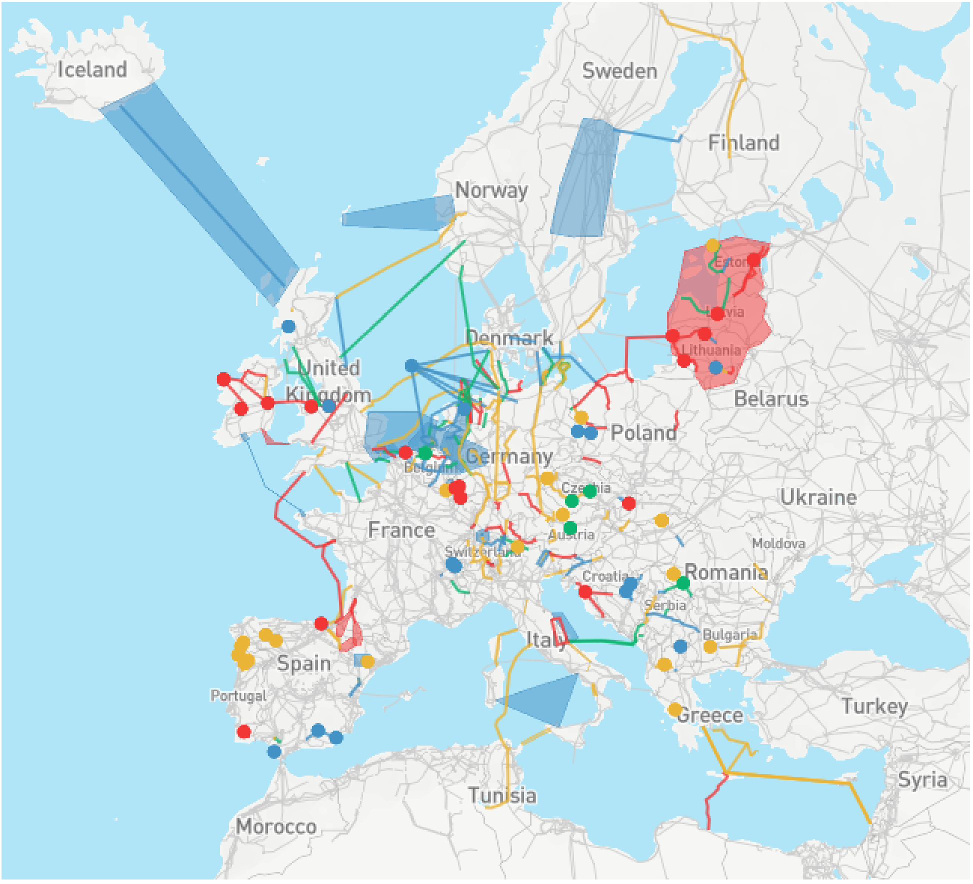

Figure 5: Planned transmission grid in Europe. Shown new grid connections are either in planned, under consideration, in permitting or commissioned. [9]

As we can see in the picture 5 most of the new grid connections are from the north to the south. That has prosaic reason. In the north is enormous hydro potential in countries like Norway. In the north is also wind potential, in the form of off-shore wind power plants. In the south is on the other hand PV potential. In Austria is then hydro potential that should be used to a higher extend in the future. We can also see that many lines are planned under the sea. This is due to the fact, that the connections under the seas are still not strong enough but also because none is protesting, when the grid id being build under the water (unlike Suedlink in Germany).

Logic behind the more connected grid is that sun may not shine all day in one small part, but there's much bigger probability, that it will shine at least somewhere in Europe. Same applies to wind. Then with sufficiently large installed capacity is reduces the necessity to use conventional power plants that burn fossil fuels. It also reduces necessity to build lots of new additional storage. Which would be extremely expensive, to say the least.

4 Czech Republic

4.1 Transmission grid

Transmission grid (TS) in CR is 400 and 200 kV based circular system (There are always at least 2 points or sides it's connected to the rest of the transmission grid. This prevents blackout in the case of grid failure on one side). It transmits electricity all over the country and it's connected to the integrated European grid. It supplies energy to the distribution grid which supplies energy to the end consumers.

TS is connected to all of the neighbouring countries and is integrated in all of the continental Europe transmission grids. Sole owner is the state of Czech Republic and the TS operator is called ČEPS. [4]

The situation mentioned above translates of course also to the conditions of Czech republic and it's plans of grid development. [13]

4.1.1 Current state

Length of the TS is 3737 km for 400 kV and 1942 km for 220 kV. There are 41 distribution centres and 78 transformers with installed capacity of 26 100 MVA.

Variability of capacity flow through CR has been rising steadily. This is due to the high installed capacity of wind power in northern Germany, high import of states of South Europe and combined with insufficient transmission capacity inside of Germany. From the year 2017 are in the distribution centre in Hradec PST (phase shift transformers). Their task is to eliminate negative influence of fluctuating flow through CR. [13]

4.1.2 Development of TS

development of PS	**year 2018-2025**	**year 2025-2050**	
doubling the capacity existing transmission line:	239	797	
new double or single transmission	174	161	
renovation of curren transmission lines	423	405	**[km]**
rebuild from 220 kV to 400 kV	157	0	
sum	**993**	**1363**	

Figure 6: TS current state and future development data. [13]

In the following figures is possible to see current and planned development of Czech transmission grid. Prediction is taking into account not only power generation from renewable but also expected rise of electromobility and sustainable heating. As we can see, the lines in the CR are build in west-east direction. This is reminiscence of the former Czechoslovakia arrangement of the grid. Where most of the power plants were in north-west of the country and the power was delivered to Slovakian part. There is very weak connection from the north to the south, because it wasn't needed in the past. Now-days, it would be needed but it moved from technical to public relations problem. Public (or landowners) are simply not in favour of building new TS in their backyard (NIMBY). Similar problem apply to whole EU.

As we can see in the figure 8, 9 and table in the fifure 6, the 220 kV TS lines are supposed to be replaced with 400 kV lines. This should help increase the capacity of the grid, without necessary building new routes for TS lines. (which as mentioned above is source of public resistance)

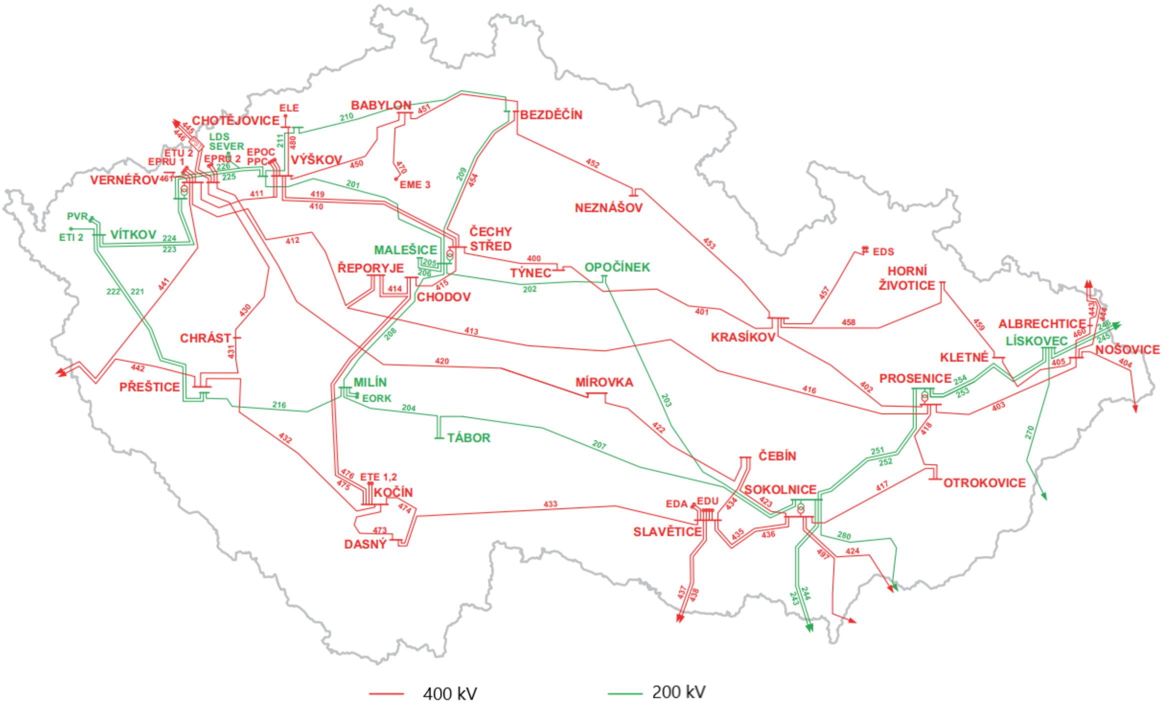

Figure 7: Transmission grid of Czech Republic in 2018. [13]

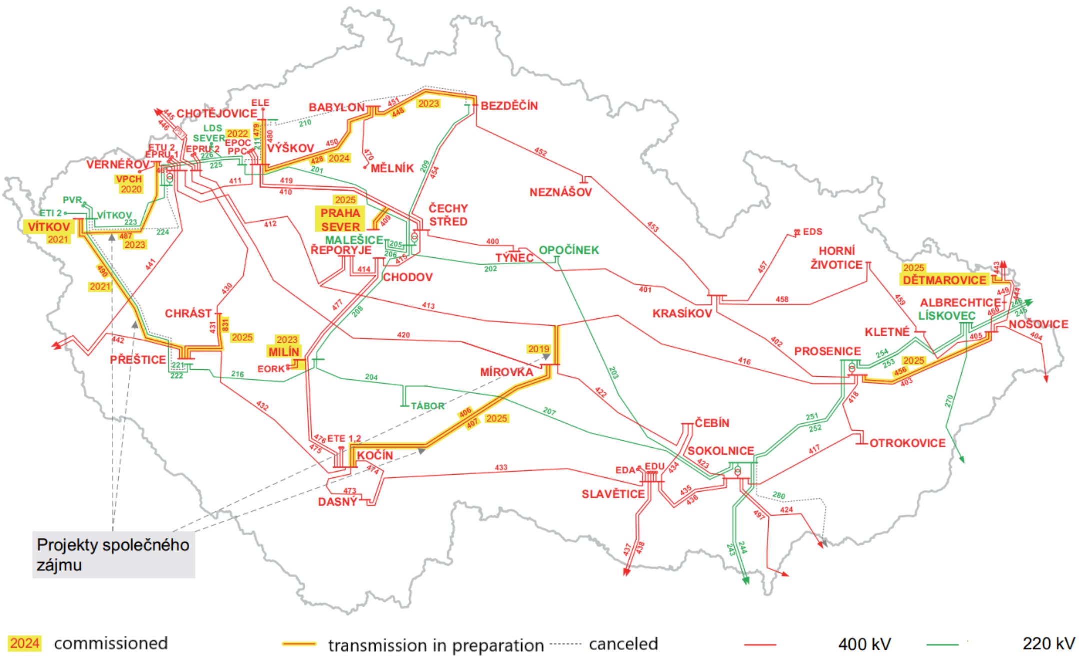

Figure 8: Planned transmission grid of Czech Republic in 2025.[13]

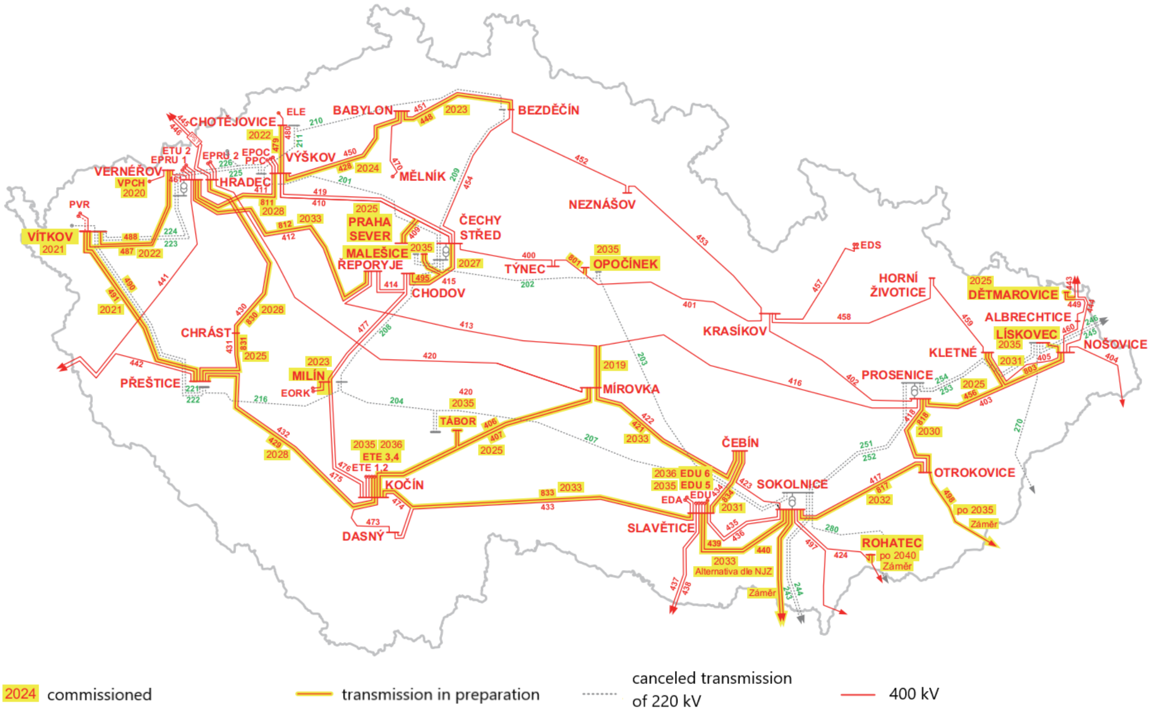

Figure 9: Planned transmission grid of Czech Republic in 2050.[13]

However not only building new transmission and distribution lines can lead to the desirable end. Grid can be optimised also in other ways. One of the very promising ways is better mathematical models of the grid and better use of the current grid. This concept is called smart grids. On the area of CR exist only few case studies. For example in Pisek (E.On distribution). Challenge is nonetheless to be able in real time optimise the flow based on the enormous amounts of data from smart meters. This could be solved for example by locally computing the data and then sharing just the values that are necessary for the grid power planning. This would also solved the great problem with privacy and smart meters.

4.2 Renewables

Czech republic has very little renewable potential. Basically the only economical potential concerning renewables lies in bio-mas. There is also very little realistic pumped hydro or hydro potential that hasn't been already used or is not in some area, where it's not from environmental or political reasons possible. Czech republic has relatively good infrastructure, which is an inheritance, after it's communist era. Coal power plants are getting old and will be needed to be replaced (also because of the environmental reasons). Considering the fact, that other surrounding countries are also planning to close old power-plants or will have problem with satisfying their own energy needs; the Czech Republic can't rely on energy supply of other states. It needs to build it's own power generation power plants. Lately has been widely discussed the possibility to build new power-blocks in addition to one of it's nuclear power plants.

4.3 Old power plants

Big chunk of the power-plants was build or at least planned during the communist era. This means that the power-plant base is starting to get old and will be needed to be replaced in the foreseeable future.

4.4 Conclusion for Czech Republic

Czech Republic (CR) has close proximity to Germany and Austria, is deeply integrated in European market and has lack of natural possibilities for renewables. At the same time it needs to keep it's high standard of national energy security.

CR is in between Germany and Austria. Insufficient transmission routes from Germany to Austria are putting CR in a tough spot, therefore it needed to protect it's own grid and installed PST at it's borders with Germany to limit potential catastrophic effects of the German implementation of renewables. CR also needs to strengthen it's transmission grid and push through the ”NIMBY” limitations of building new lines.

Lack or natural opportunities for it's own intermittent sources of energy is putting CR in a tight spot and this might be the catalyst for future further development of nuclear energy generation.

5 Austria

5.1 Transmission Operators

In Austria are to Transmission Operators one of them is the Austrian Power Grid (APG) which is responsible for 8 of the 9 federal states. The Vorarlberger Übertragungsnetz GmbH (VUEN) [10] is controlling the power flows in Vorarlberg and has a cooperation with the APG since 2012. Reason for the special cooperation is the geographical location of Vorarlberg.

5.2 Transmission Grid

The Transmission Grid in Austria is consisting of the highest Voltage level with 380kV, a lower level of 220kV and 110kV. These both are the backbone of the power supply. This includes a system length of 6970km and approximatly 3500km of marked-out routes. The 380kV is built like a ring to supply from two points if necessary, but this ring is not closed now.
Austria is in the central of Europe and so a big player for transmitting energy through pan-Europe. In this situations the 380kV and 220kV lines are used and must be managed very carefully because of the national and international power flows.
All this actions and many more challenges are done by the APG, but there are also regional transmission operators in each federal state. These operators are then handling the voltage levels from 110kV to the consumers voltage level of 230V. For the countryside the regional operators are using mashed and stripe transmission lines. The reason for not using ring systems is the high price of the infrastructure compared to the quality of supply, what means only few consumers which are not as addicted to a high security of supply as hospitals and industry.
One disadvantage of stripe lines and mashed systems is the feed in of the renewables like photo voltaic which are populare at the countryside. In such situations of high decentralised energy producers the local TSOs has to handle this with improvement of energy infrastructure at transformers, transmission lines and demand side management.
The Austrian power systems has a high quality transmission system, which works really well and with a level of security. Nevertheless it is mandatory to improve this system. There a several challenges to cope some of them are listed in the Network Development Plan or Masterplan from APG.

- saving the security of supply
- saving of the voltage quality
- handling of volatile energy generation from sun and wind
- handling of distributed energy producers
- implementation of network codes

5.3 Distributed energy producers

The integration of the renewable energy sources especially photo voltaic is in Austria supported from the government. Therefore a lot of households which are annually installing new pv-plants on their roof 10. This kind of energy producers are called decentralised power plants and are really difficult to handle. Reason for that is a law called the EEG which is an european guideline 2009/28/EG. In this guideline is written that all renewable energies has to be used first and then other fossile, hydro or nuclear energies are allowed to use. This brings us to the problem that we need a forecast with a high quality to set a possible energy schedule. In the case that we do not have the expected weather on the next day the TSO has to improve to balance the grid system. Furthermore the pv-systems are huge reactive power producers, which leads to a big problem by building up the grid after a blackout.

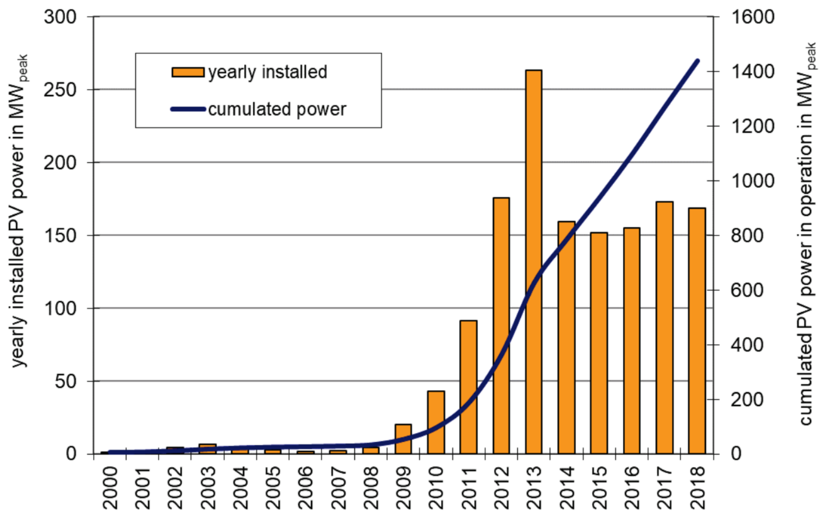

Figure 10: installed Energy in Austria over the last years [3]

With every year more and more pv-systems are going to be installed and the volatile energy feed-in and reactive power is increasing. So the grid operators needs to improve their systems to cape with these challenges.

5.4 Energy generation from wind

In Austria we have now a total peak energy production of more than 3000MW. This wind power plants can produce 7 TWh per year which is the amount of 11% total amount of energy consumption in Austria [**innovativeEnergietechnik**]. But therefore you also need perfect wind conditions to reach such dimensions.

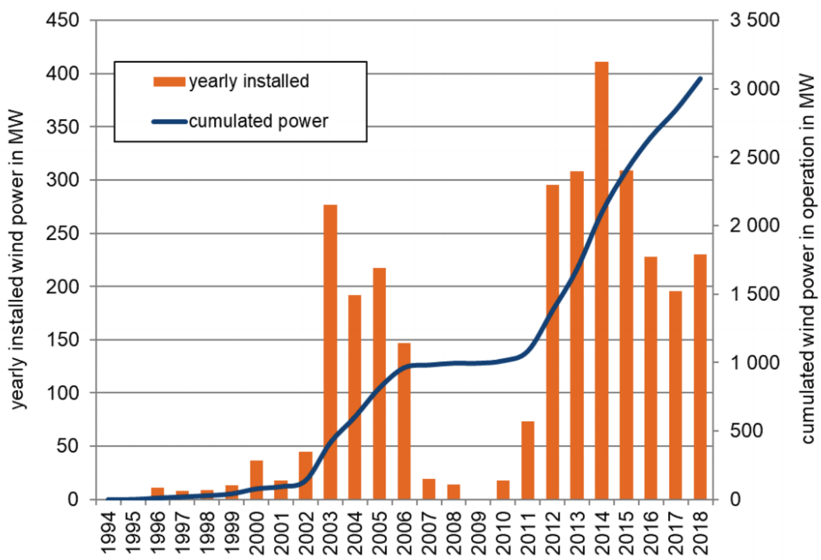

Figure 11: installed wind energy in Austria over the last years [3]

As the figure 11 shows the production of wind generators is decreasing, what is actually good for managing the energy flows. The wind generation is even more difficult to handle than pv-systems.

First the pv-systems are divided in whole Austria, so the feed-in is also distributed, compared to wind farms which are build concentrated in the east of Austria. Therefore the produced energy has to be first transferred through transmission lines to the areas with high consumption. Second sun prediction is much more easier than wind prediction and even not so volatile.

5.5 Projects for Austria

In Austria are many projects planned for the next years. Nearly every distribution operator has to improve his grid system with security equipment and transmission lines for the volatile and decentralised renewable energies. In this section I will focus on the biggest ones from APG and two other distribution system operators. This projects are also subsidised from the european government and have the status of project of common interests (PCI).

5.5.1 380-KV transmission line St. Peter - federal border

The german connection to St. Peter will be massive improvement for the connection between bavaria and the pump hydro storages in the alps of Austria. This transmission line is one important action to handle the situation of energy excess from wind generation in the north of Germany and also necessary for German nuclear power exit.

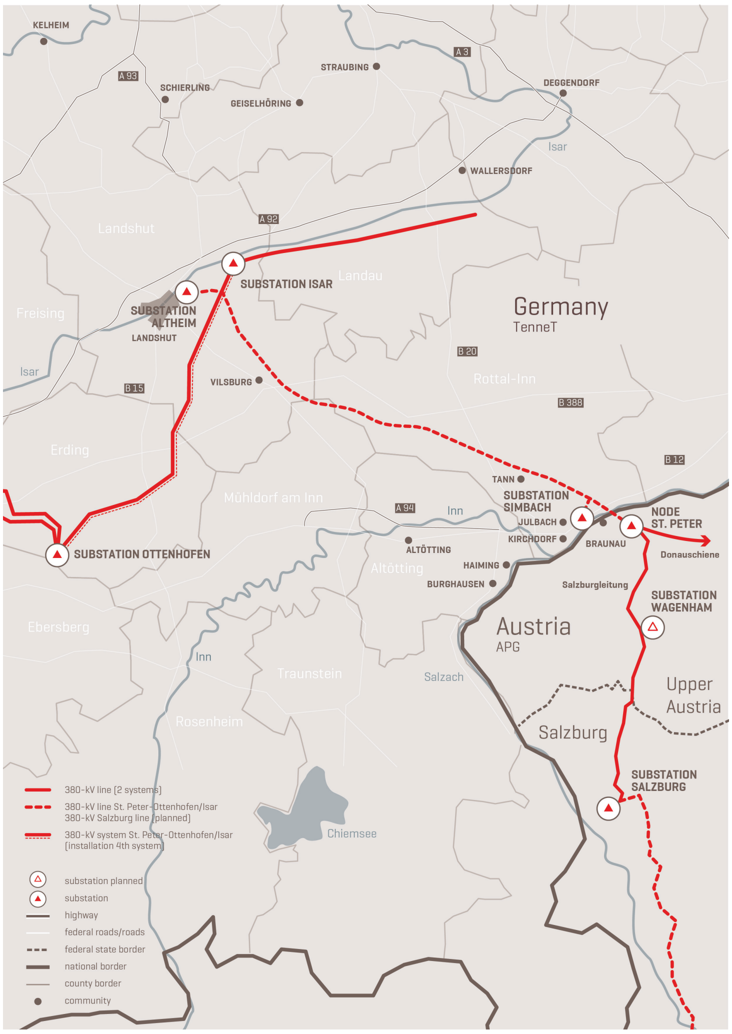

Figure 12: Transmission line to St Peter and further to substations Altheim Germany

This project is together with Tenne T which is one of the German TSOs. The APG is building the line to the federal border an Tenne T is doing the same for their side.

5.5.2 380-kV-Security-Ring

Since 2012 the APG is trying to find a way how to convince the people in Salzburg that this transmission line is very important for the national power system [1]. On 5 March 2019, the federal administrative court in Vienna upheld this intention for one of the most important infrastructure projects. After a positive environmental impact assessment (EIA) the closing of the 380kV transmission line in the area of Salzburg get green light.

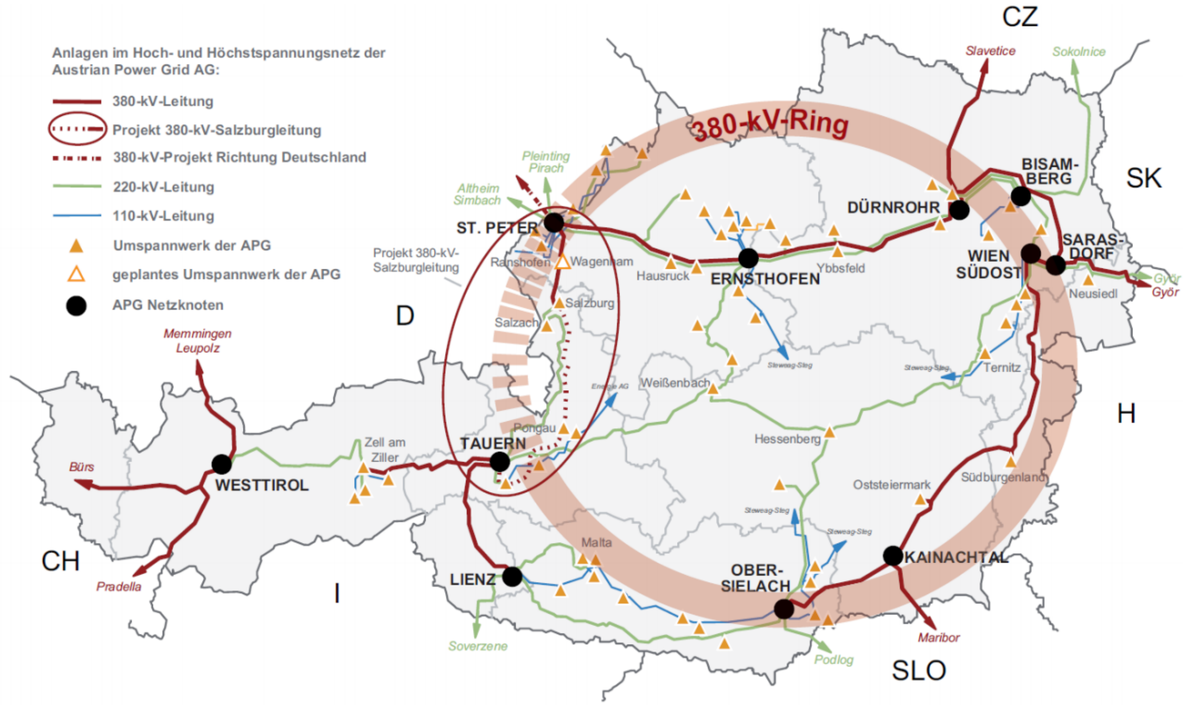

Figure 13: Security ring in Austria with 380kV

There is also a part in Carinthia which is not closed. It is from Lienz to Obersielach, this would be the last gap for a closed ring.

5.5.3 Netintegration of EE East of Austria

Another PCI project is the integration of wind energy in the east of Austria to provide a security supply to electricity demand areas. The second reason for this integration is to improve the connection of Hungary. As already described the volatility of wind is a big challenge for TSOs and need a stable and good handling of the grid in this wind energy parks.

5.5.4 Hydro Pump Storage Power Plant Pfaffenboden in Molln

The Hydro Pump Storage Power Plant Pfaffenboden in Molln will have an installed capacity of +314/-320 MW that is provided by 2 reversible Francis-Pump-Turbine [8]. This project is important to handle the renewable energy express and is also a really nice project how implementation of hydro power plants in nature could be. This system will improve the flexibility and stability because of the type as hydro pump power plant. This power producers can ramp up quickly when the grid needs urgent feed in or consumption of electricity.

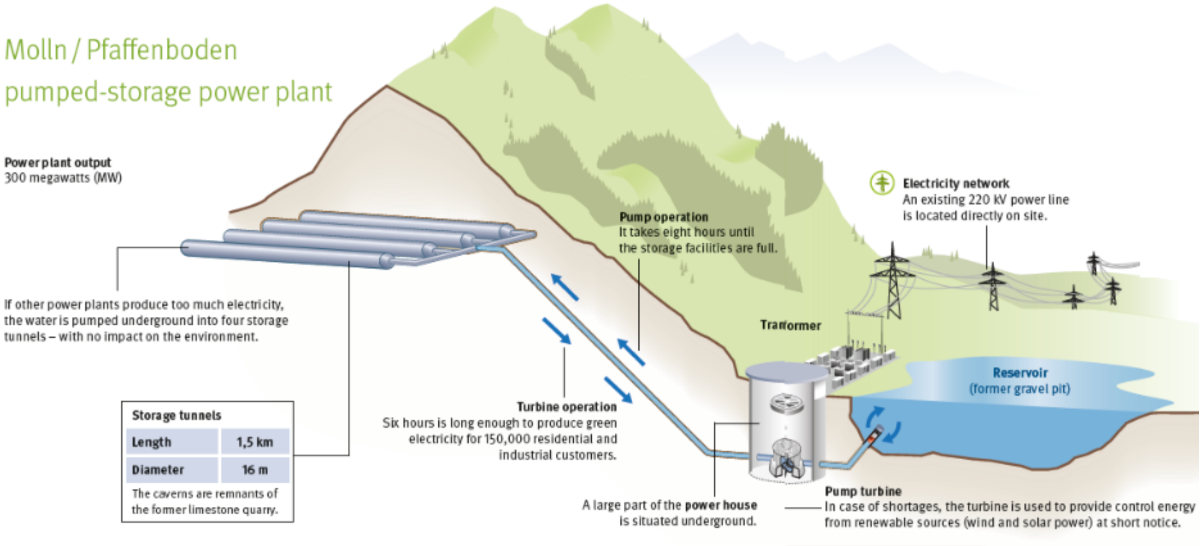

Figure 14: Hydro Pump Storage power plant Pfaffenboden

In the picture 14 you see that tunnels are drilled into the mountain for the water storage. Also the pump station is below the earth level and well integrated in nature. Unfortunately this project has been stopped for undefined time, reason is the search for a new investor. [12].

5.5.5 Extension hydro storage Kaunertal

Founder for this project is the Tirol Wasserkraft (Tiwag), which is the distribution operator of Tirol. Now a water reservoir with the capacity of $138\ Mio\ m^3$ called Gepatsch and a output engine power of 392MW is installed. To extend the water reservoir a new one with the capacity of $43\ Mio\ m^3$ called Platzertal will be installed [15].

Furthermore a pump-turbine engine in the area of Versetz with a power output of 400MW and also a turbine at Prutz 2 will increase the power plant with 500MW. In the following picture red colored the improvements of the power plant.

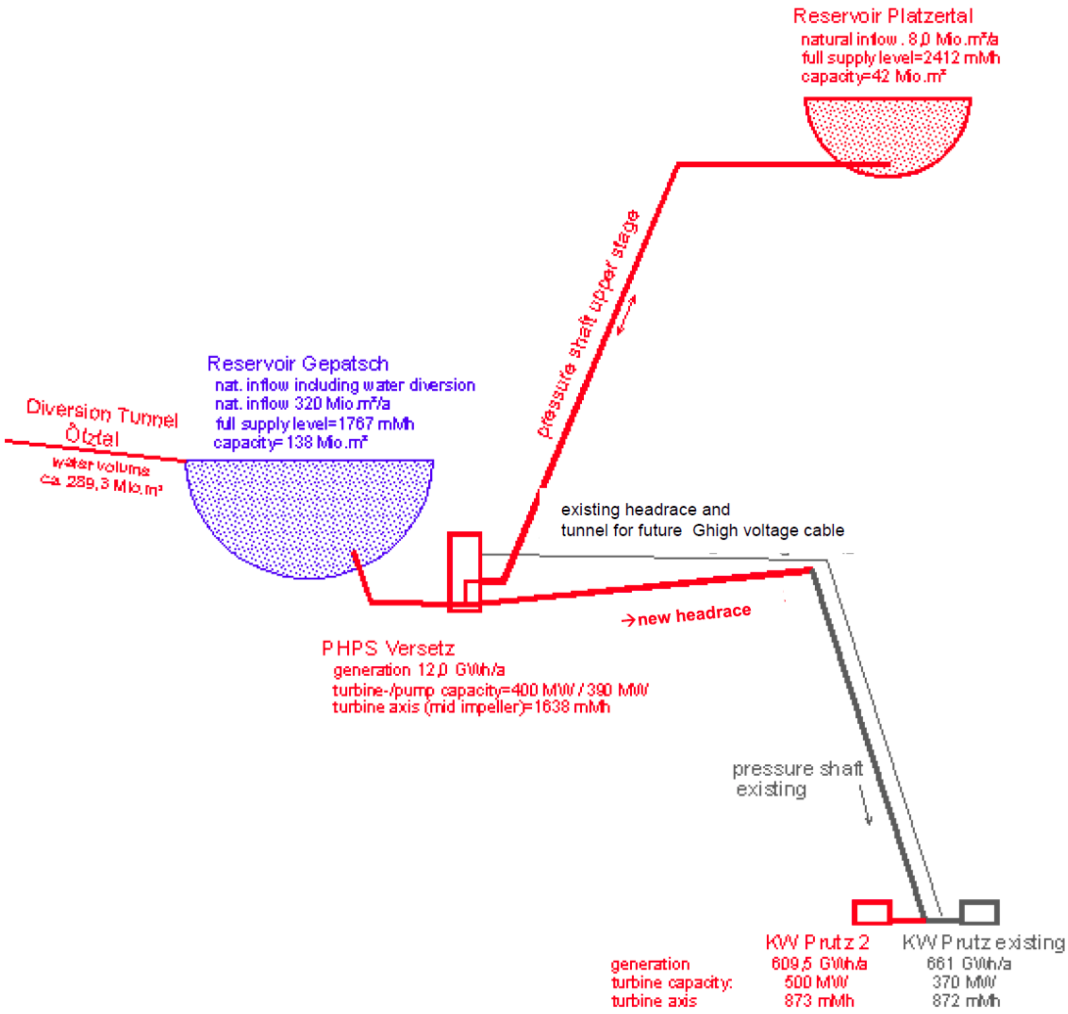

Figure 15: Extension of the hydro storage Kaunertal

Another benefit is the flood control measures for the Oetztal, Kaunertal and also the Inntal, which is improving safety for residents in these regions. This project has also the status of a PCI project.

5.6 Conclusion Austria

Austria PCI projects are located in the field of handling volatile energy flows. As mentioned above most of them are hydro storages and grid extension. However these are only the projects which are now in the list of ENTSO-E projects of common interests. It will be really interesting how the DSO's will handle the increase of electro mobility. In case of a huge increase of electric cars it will be necessary to make our grids even more stable and strong. Especially in cities like Vienna, Graz, Salzburg and Innsbruck the infrastructure of transmission lines must set to complete new dimensions to cape with the new demand of energy flows. Finally there are decarbonisation goals which has to be reached in the next years. This is only possible with renewable energies, like PV or wind generation. Another option could be green gas, but nowadays it is to expensive and not economical. The future will show us which existing technology will be the big player or players in the field of energy production or if a new product will change the situation completely.

References

[1] APG. *380-KV SALZBURG LINE*. 2012. url: https://www.apg.at/en/projekte/380-kV-salzburgleitung.

[2] APG. *Balancing*. 2015. url: https://www.apg.at/en/market/balancing.

[3] Peter Biermayr et al. "Innovative Energietechnologien in Österreich Marktentwicklung 2013". In: *BMVIT Schriftenreihe* 11 (2015), p. 2015.

[4] ČEPS. *Deseiletý plán rozvoje přenosové soustavy České republiky 2017-2018*. 2018. (Visited on).

[5] E-Control. *Die 20-20-20-Ziele*. 2018. url: https://www.e-control.at/konsumenten/oeko-energie/klima-und-umwelt/20-20-20-ziele.

[6] ENTSO-E. *Members*. 2015. url: https://www.entsoe.eu/about/inside-entsoe/members/.

[7] Entso-E. *R&I Roadmap 2017-2026*. 6.2016. url: http://riroadmap.entsoe.eu/wp-content/uploads/2016/06/entsoe_ri_roadmap_2017-2026.pdf.

[8] entso-e. 2019. url: https://tyndp.entsoe.eu/tyndp2018/projects/storage_projects/1000.

[9] entsoe. url: https://tyndp.entsoe.eu/tyndp2018/projects/.

[10] Vorarlberger Übertragungsnetz GmbH. *Regelzone*. 2012. url: http://www.vuen.at/de/.

[11] oenergetice. 2019. url: https://oenergetice.cz/energostat.

[12] ORF. 2017. url: https://ooe.orf.at/v2/news/stories/2851750/.

[13] OTE. *Očekávaná dlouhodobá rovnováha mezinabíkou a poptávkou*. 2018. (Visited on).

[14] Florian Reinke. *Electricity grid operation and its major role within energy transition. Enabling the intergtaion of renewables.* 2018.

[15] TIWAG. 2014. url: https://www.tiwag.at/fileadmin/user_upload/wasserkraftausbau/kraftwerksprojekte/ausbau_kraftwerk_kaunertal/Projektvorstellung/Kaunertal_Extension_Project_Description_Dec_2014_English_website_150119.pdf.