International electricity exchange in Europe: problems and challenges

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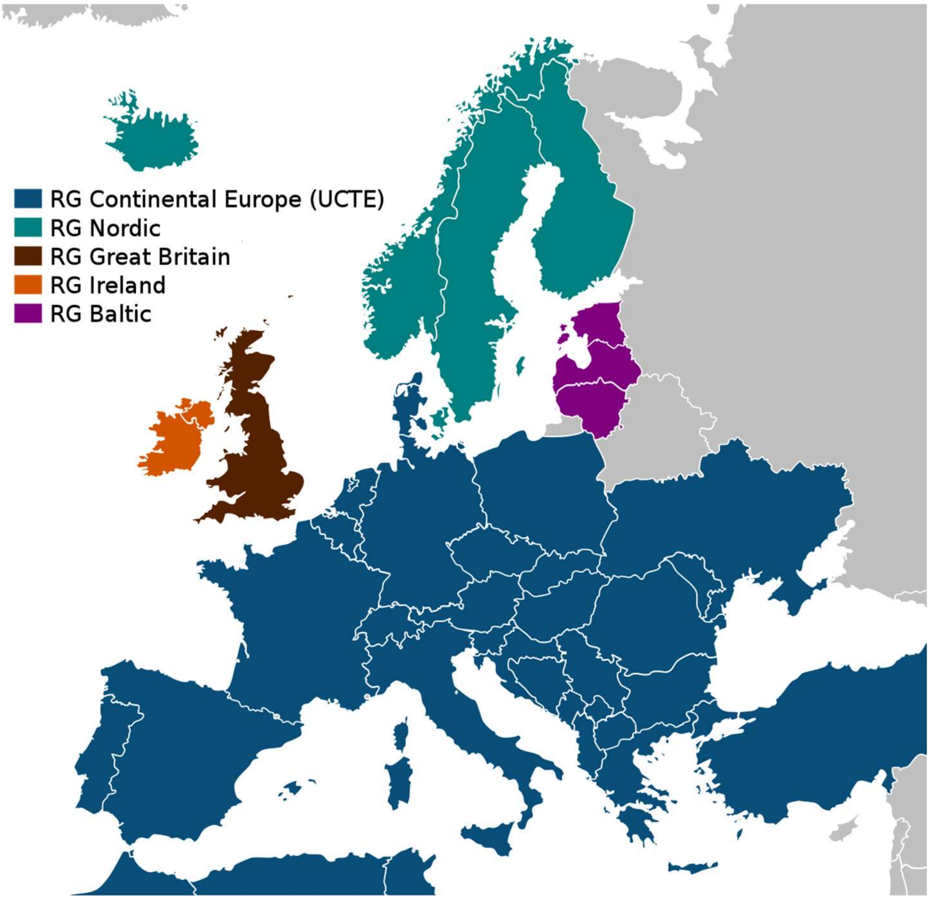

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Abstract

In this work, we want to give an overview of the electricity exchange in Europe. To begin with we give an overview of the current state of European power grids, their interconnections, and the electricity market. Next, we investigate cross-border transmission capacities, their importance, and availability. Transmission capacities are an integral part of the green transition and for supplying cheap electricity. For example, the North Sea will become a hotspot for wind power and getting the energy to where it is needed will require significantly more transmission capacity than what is currently installed. Therefore, expanding the grid needs to be a priority.

The second part of this paper will cover the major crises Europe is facing currently, the war in Ukraine and the climate crisis. The war in Ukraine forces us to reevaluate our dependencies on foreign energy imports, namely from Russia. The war also caused a big surge in electricity prices both in Austria and Czechia.
The European Union has put forward ambitious goals to reaching carbon neutrality by 2050. We will cover the different milestones along the way and the new green deal. EVs are an important part in stopping the use of fossil fuels. Their role in the energy transition will be covered as well as how they might be used for energy storage.
Lastly, we will discuss EU policy.

The current situation

Grid

Figure 2 shows the different synchronous electricity grids in Europe. As you can see there are five of them. By far the biggest individual grid is the one of continental Europe. It spans most EU member states and even countries like Morocco, Ukraine, and Turkey. Over 400 million people are supplied with electricity through it. The grid is made up of several national grids which each consist of hundreds or thousands of kilometres of high voltage and ultra-high voltage AC lines, substations, and power plants.

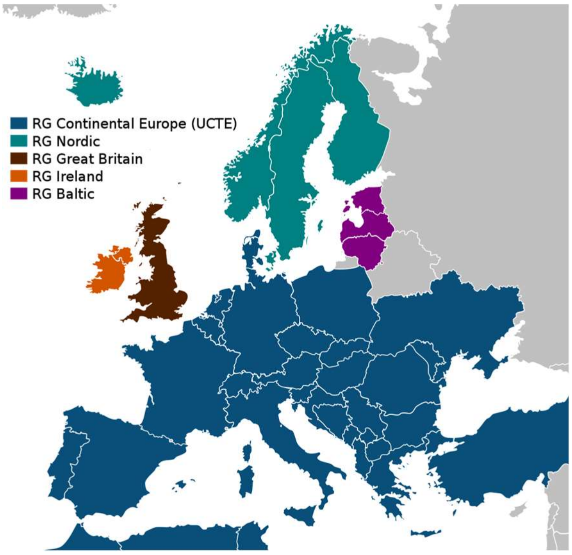

Figure 2 - Synchronous areas of Europe

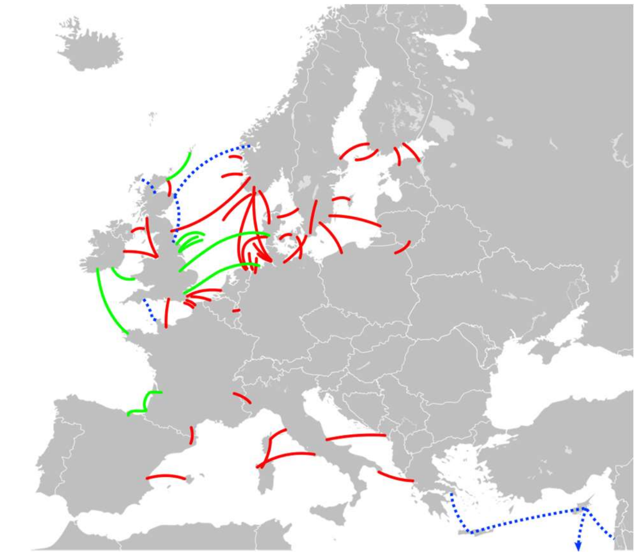

Figure 1 - HVDC lines of Europe

Within each synchronous area energy can be exchanged between countries through cross-border AC tie lines. Furthermore, there are several high voltage direct current (HVDC) tie lines connecting the different synchronous areas. HVDC lines can deliver power over hundreds of kilometres with much lower loss than AC lines. In addition, they may be used to connect grids which are not synchronized, a task which is impossible using AC lines. Figure 1 shows all HVDC connectors in Europe. Built ones are red, lines which are under construction are green and planned ones are blue. As you can see HVDC lines are not exclusively used between synchronous areas, but also within them.

These interconnections allow for electricity to be traded throughout the EU and most of the European continent. Additionally, countries may help each other in emergencies.

Market

The electricity market is structured in three-time frames.

Electricity can be traded long-term, which covers energy that is traded days, months or even years before the point of delivery. This can be used if consumption can be predicted to hedge against high electricity prices. These deals can be made at an exchange or bilaterally between two parties.

The most important public exchange for electricity in Europe is the day-ahead market. Electricity, which is to be delivered the next day, can be traded until noon of the day before. Market actors use this exchange to buy energy for the next day.

Lastly, there is intraday trading, where electricity can be traded up until 5 minutes before the point of delivery. This time frame is used to correct for unexpected increases or decreases in production or demand.

When time moves closer to delivery, prices get more volatile.

In these markets electricity can also be traded across borders, however contrary to national grids, one needs to have the right to use cross-border transmission capacities to be allowed to perform cross-border trades.

Figure 3 illustrates the different timeframes of the energy exchange.

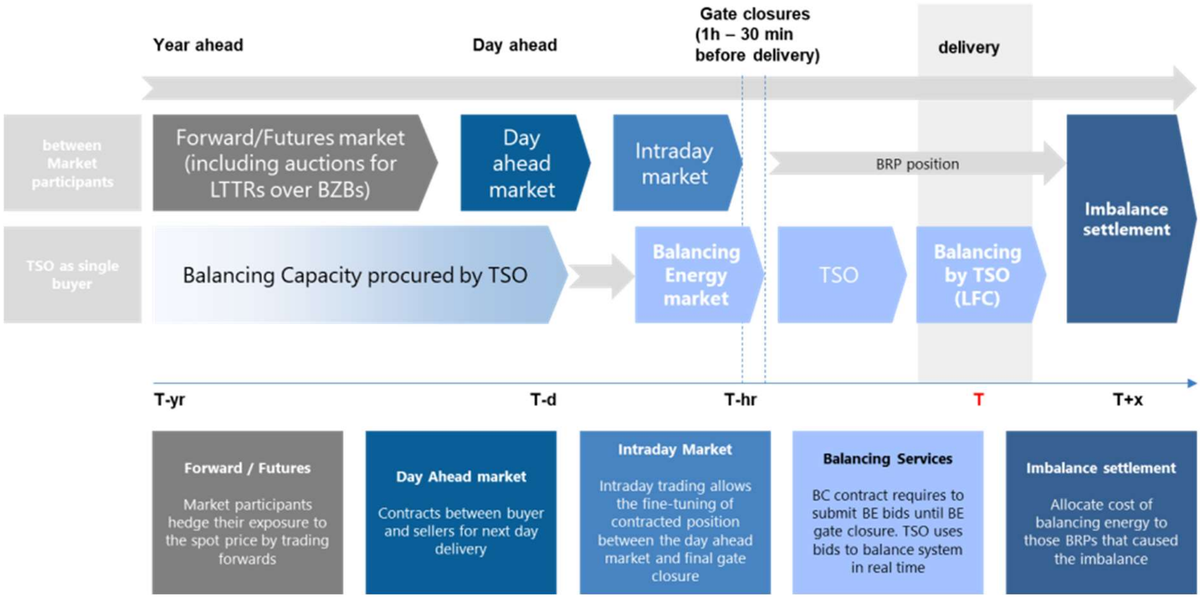

Figure 3 - Timeframes of the European electricity exchange

Trade balances

Let us look at current trade balances in the EU. We want to start by comparing Austria and Czechia and looking at the trading between the two countries.

In 2023 Austria exported 19.60 TWh of electricity, while it imported 21.80 TWh. This makes Austria a net importer by 2.20 TWh.

Czechia exported 17 TWh of electricity while importing only 7.80 TWh. This makes Czechia a net importer by 9.20 TWh.

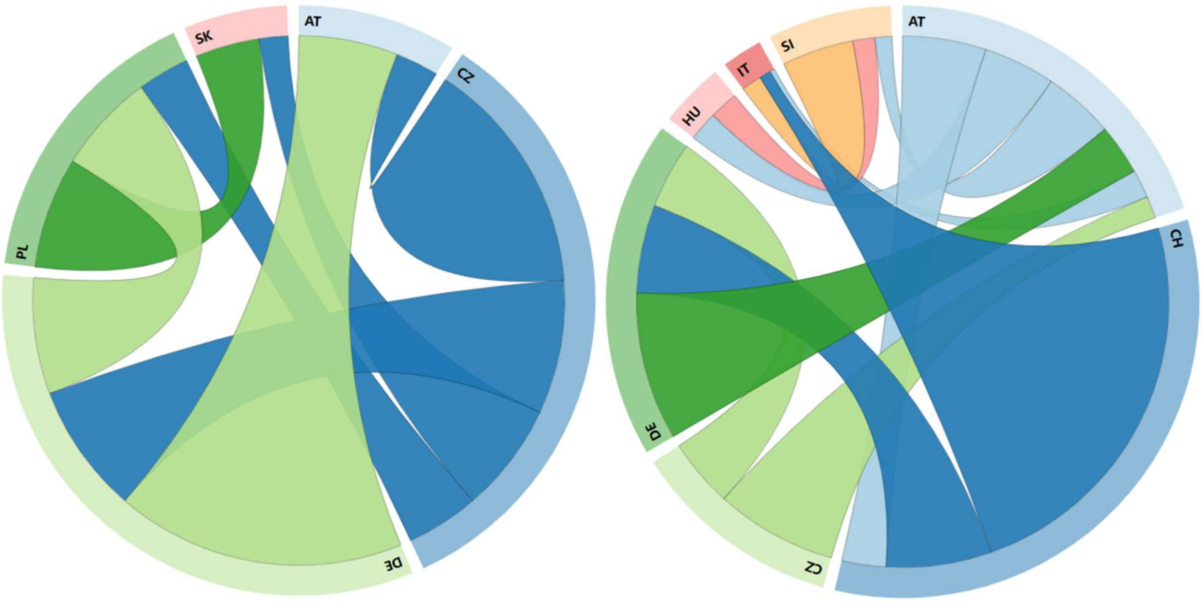

Figure 4 - Trade balances for Czechia (left) and Austria (right) for 2023

Figure 4 visualizes the two countries' trade balances.

Austria was the biggest importer of Czech electricity in 2023. Austria imported 7.28 TWh from Czechia while only 1.32 TWh were transferred in the other direction. This means there is a trade deficit between Austria and Czechia of almost 6 TWh. Despite this, Austria has a much lower trade deficit. This is because oftentimes the energy just transits through Austria and is exported again at another border.

Some other notable countries are Italy, which is the biggest net importer of electricity in the EU at a deficit of 51.30 TWh. France is the biggest net exporter with a surplus of over 50 TWh.

Foreign energy sources

The EU's electricity mixes in 2023 consist of just under a third of fossil fuels. The rest is made up of nuclear at 23%, biomass at 5,7%, hydro at 11,8%, wind at 17,6% and solar at 9,1%, as can be seen in Figure 5.

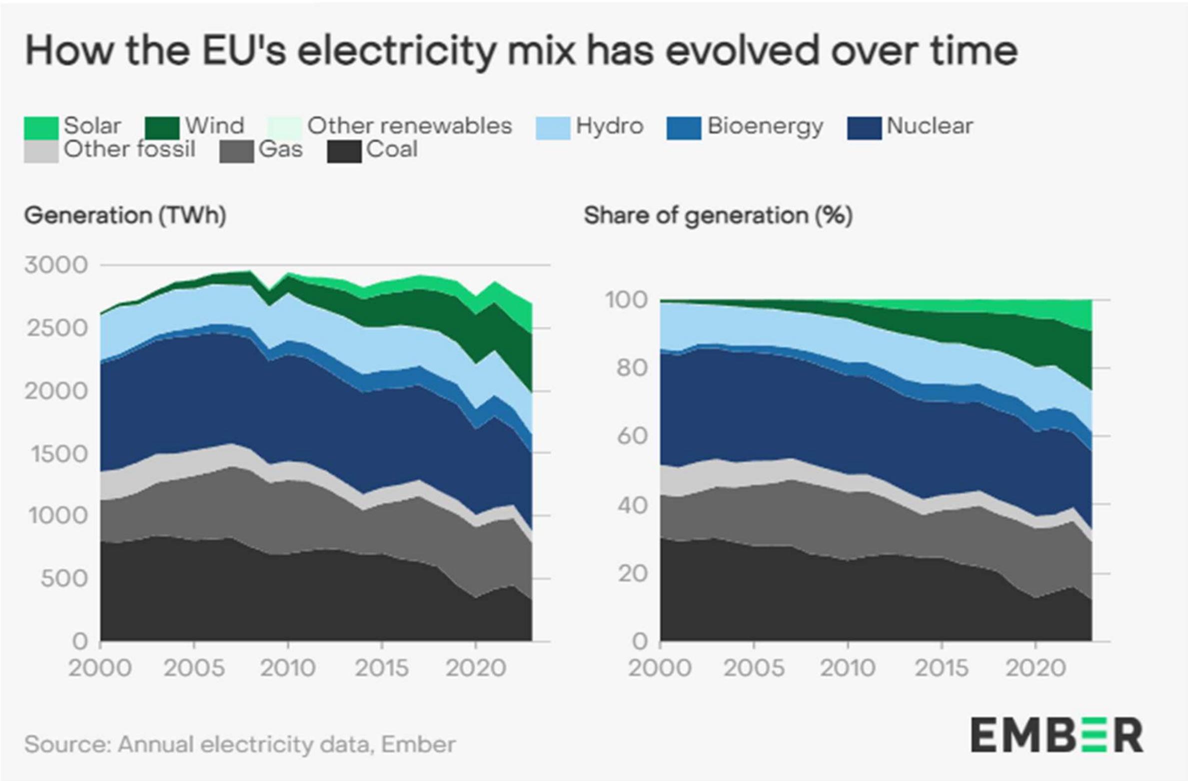

Figure 5 - EU electricity mix

Almost all the oil and gas which the EU consumes is imported from foreign countries. Both oil and gas dependency lay at 98% in 2022. After the war in Ukraine started, the EU moved away from Russian oil and gas. Today the U.S. and Norway are the two biggest suppliers of Oil and Gas for the EU.

The import dependency for coal lay at 30% in 2021. This means that Europe satisfies 20% of their electricity needs through fossil fuel imports. Almost all uranium used in EU nuclear plants is also imported (97%). This results in around 40%-45% of European electricity being generated from imported sources.

Transmission capacities for cross-border trading

Increasing electricity trade across European borders is a major EU goal. This is because trans-European electricity exchange provides great value for the EU.

For example, a German wind farm in the Baltic Sea could export the very cheap electricity it produces to Poland for a big profit margin. At the same time the Polish company achieves a lower price for the energy compared to buying it domestically, therefore, for these two market actors both producer and consumer welfare are higher than they would be without the cross-border trade. Through this, the market optimises which power plants are operated on any given day to supply Europe with the cheapest electricity possible. If the transmission capacities are not strong enough between countries, suboptimal power plant usage will be the result. This would lose European economies a lot of money as cheap power plants are standing still while expensive power plants are run at a great cost, thus lowering socio-economic welfare.

From an environmental perspective cross border trading is also a must-have. This is because renewable generation is heavily dependent on the weather and therefore it is often geographically bound to a specific region like the North Sea. Electricity must be transmitted over long distances and across multiple national borders to supply all of Europe sustainably. Other times there will be a lot of sun in Iberia, or the Balkans and this energy has to be distributed to all of Europe. If the tie lines between countries are too weak to transmit renewable energy, parts of Europe which currently are not experiencing favourable conditions for renewable generation will have to fall back to conventional power plants using fossil fuels. This will hurt the environment and CO2 will be emitted which could have been avoided by stronger interconnection. Figure 6 shows possible focal points of different types of renewable generation.

Lastly, strong transnational connections help in case of emergency. Should any nation experience an accident or otherwise have either a great surplus or deficit of energy, neighbours can help. For example, if a big nuclear reactor must be shut down, a significant generation capacity is lost. Now the affected country needs to resupply through different means. One option to do this is through transnational electricity trade. Furthermore, if two countries have a matching deficit/surplus in opposite directions, cross-border transmission allows for no action to be necessary as the two errors compensate.

As you can see, cross border trade of electricity is essential for a sustainable and safe future European grid which generates as much socio-economic welfare as possible. For this reason, the EU has committed to making 70% of physically available cross-border transmission capacity available for trading.

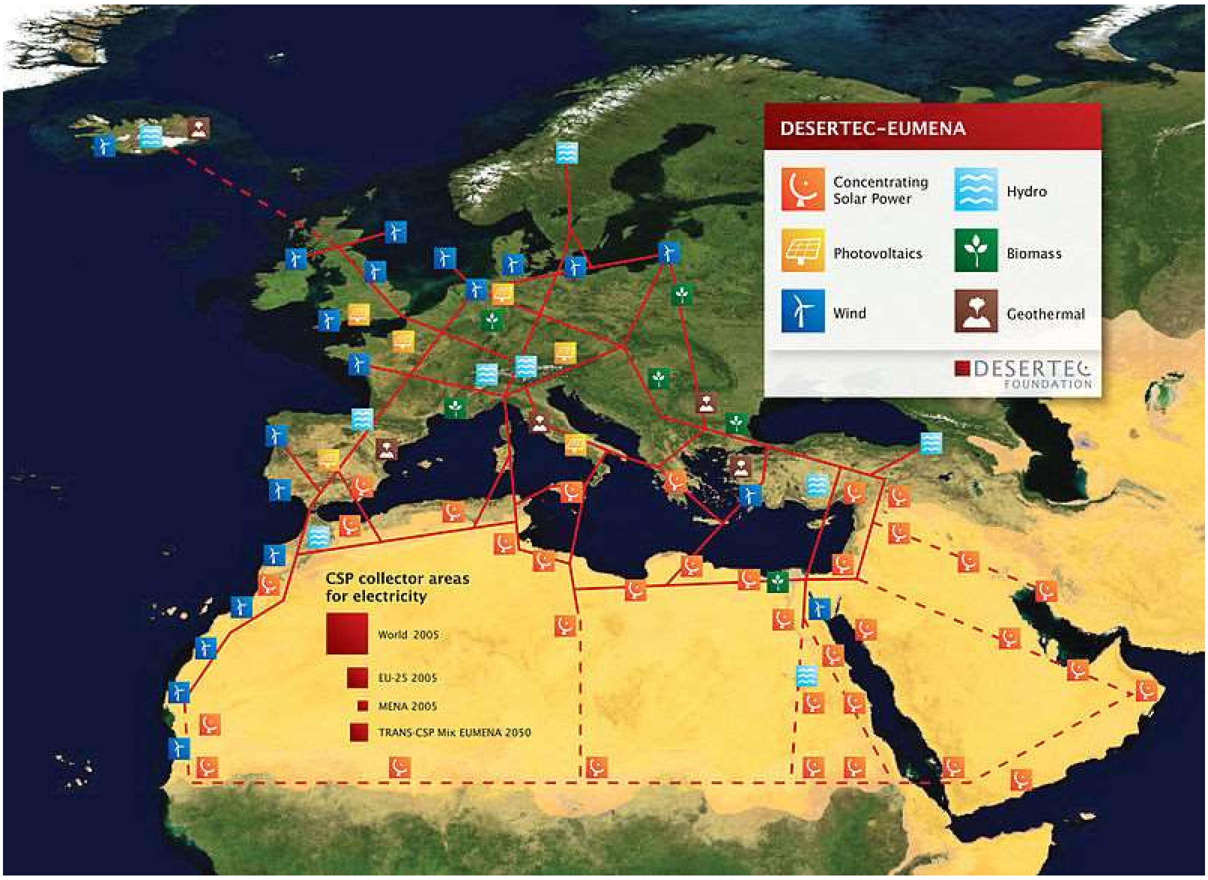

Figure 6 - The desertec proposal for possible locations of renewable generation

Currently, the physically available transmission capacity is not used fully. This is because the national transmission system operators (TSO) reduce the available margin of the cross-zonal trade (MACZT) for different reasons. Figure 7 shows the actual MACZT from 2023 for countries of the core region.

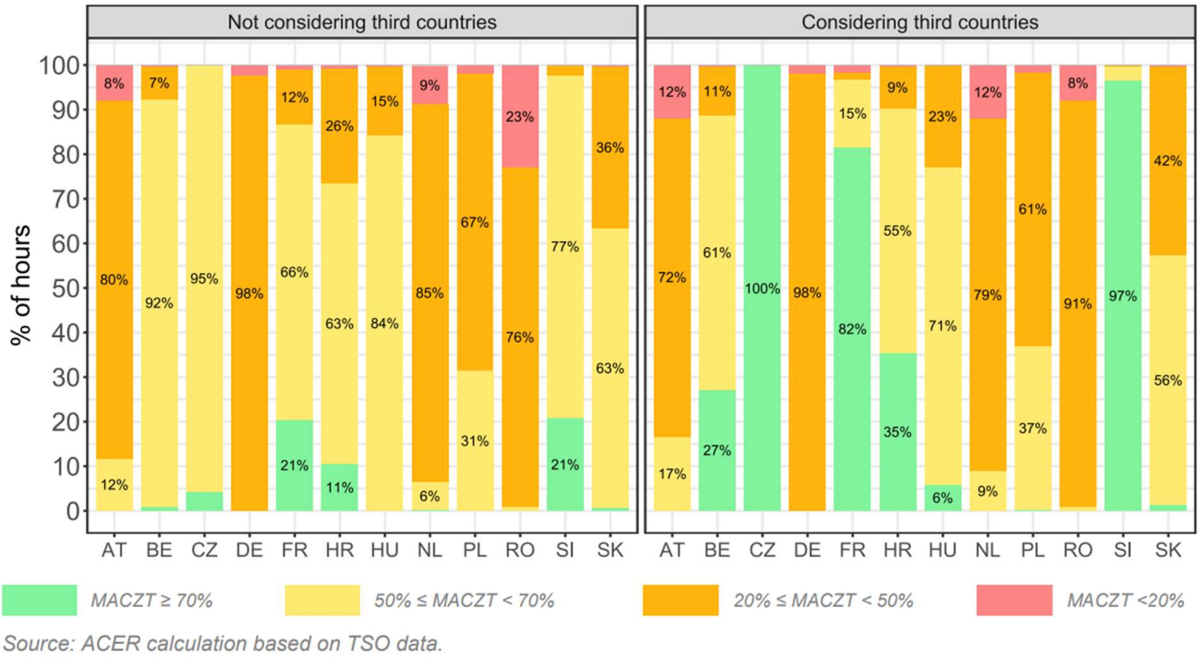

Figure 7 - MACZT for countries of the core region

As you can see most countries regularly limit their capacities. Czechia, Slovenia, and France perform quite well, reaching the target of 80%-100% of the time when considering third countries. On the other hand, countries like Austria, Germany, the Netherlands, or Romania rarely even reach above the 50% mark. It is safe to say that most countries do not reach the target.

The reason for low the MACZT are mainly critical network elements (CNE) that are carrying too much load. To guarantee safety of supply the TSOs maintain a safety margin when operating the grid. If the load values get too high, remedial action is necessary. One such action is the curtailment of transnational capacities.

The CNE can be either cross-border or within a nation. When it is within a nation, that means that the national grid is not strong enough to transmit the energy that could be imported. Specifically for Austria, this is the limiting factor most of the time. While Austria has strong transnational connectors to Germany, Czechia, Hungary, Slovenia and Switzerland, the domestic grid is not strong enough to fully utilise these assets. Czechia, on the other hand, does not encounter such problems. While also having significant cross-border capacities, the Czech grid is strong enough to transmit any imported energy. This comparison shows that to facilitate increased trans-European electricity trade we not only have to expand cross-border connections but also improve the national grids.

Autarky and green transition

The international electricity exchange in Europe is essential for European energy autarky and a zero-emission electricity supply. Without transnational trading, any renewable generation will be substantially less effective, than with it. Trading the energy is always a preferable alternative to storage options. Furthermore, due to the dependency on good generation conditions it is crucial to be able to utilise all the supply of wind or solar energy when it is available. To reach zero emissions we need to be able to exchange electricity throughout the continent on a large scale.

The same goes for autarky. Through drastically increasing renewable production, the EU can largely become independent of foreign energy imports. And again, renewables are only enabled through European energy exchange which requires a strong trans-European power grid.

Current problems and challenges

The world right now is facing many problems, which are affecting the electricity market. War in Ukraine, War in Israel, climate change, migration and so on. Some of these problems play a crucial role in geopolitics, international affairs and in pricing of energy.

War in Ukraine

The EU and its member states strongly condemn Russia's brutal war of aggression against Ukraine and the illegal annexation of Ukraine's Donetsk, Luhansk, Zaporizhzhia and Kherson regions. They also condemn Belarus' involvement in Russia's military aggression. Since February 2022, the European Council and the Council of the European Union have been meeting regularly to discuss the situation in Ukraine from different perspectives. EU leaders demanded repeatedly that Russia immediately cease its military actions, unconditionally withdraw all forces and military equipment from Ukraine and fully respect Ukraine's territorial integrity, sovereignty, and independence. In response to the military aggression, the EU has massively expanded sanctions against Russia, by adding a significant number of persons and entities to the sanctions list, and by adopting unprecedented restrictive measures. EU has imposed 13 packages of sanctions since beginning of the war[1]. Both Austria and Czechia have been steadfast allies for Ukraine over the period of War in Ukraine, providing them with financial, military, and medical support. Also, both countries were affected by energy prices[2].

Russia

Aggression in Ukraine showed countries of EU, that Russia is indeed not a reliable supplier of energy and gave Europe a reminder of their values and political goals, which are indeed not in alignment with European ones. Therefore, EU decided not to finance Russia's War in Ukraine by importing their energy resources. *Two years on from Russia's invasion of Ukraine, trade in energy products between Russia and the European Union has largely disappeared. The EU has adapted remarkably well to a decoupling that many would have considered impossible. Russia has redirected oil exports to Asia but has not been able to replace Europe for its natural gas exports. The EU reduced imports of Russian fossil fuels from a high of $16*

[1] https://www.consilium.europa.eu/en/policies/eu-response-ukraine-invasion/
[2] https://www.bmf.gv.at/en/press/press-releases/2023/October-2023/Austria-is-supporting-reconstruction-in-Ukraine-and-Moldova-with-40-million-euros_1.html

billion per month in early 2022 to around $1 billion per month by the end of 2023. Cuts to oil imports accounted for the largest part of the reduction[3]*.*

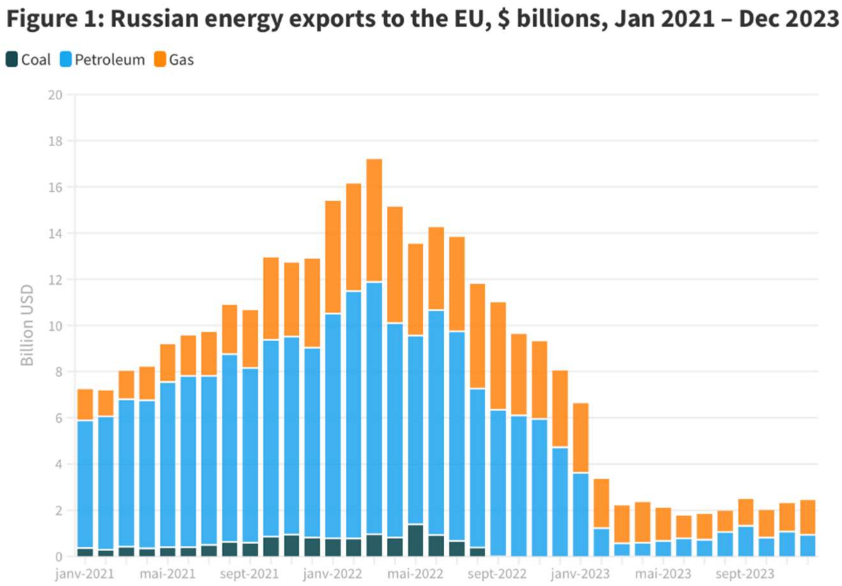

Figure 8 - Russian energy exports to the EU

Price development in Czechia and Austria

Due to Russia's invasion of Ukraine, Czechia experienced a rapid growth of energy prices. Shortly after the war started on 24. February 2022, the price of electricity on the PXE (Power exchange Central Europe) market rose up to somewhere around 200 EUR per MWh. Worst increase of energy prices was yet to come, because on 26. August 2023, for one day, it reached a new height of more than 950 EUR per 1 MWh, but then then it quickly dropped back to around 500 EUR per 1 MWh level.[4] From the beginning of December 2022, the price started to decrease to a level around 150 EUR per 1 MWh and in February, more than a year after a War in Ukraine started. From then the electricity price was only decreasing and as of April of 2024, it is now around 85 EUR per 1 MW. Market coupling is high due to sufficient cross border capacities which lead to a small price spread. So, Austria had a similar price development to Czechia. However, if we take pricing power into account, it is safe to say, that Austria lasted through this period of high prices better than Czechia did. Only country in Europe with worse rise in energy price, when we take pricing power into account, was Romania. Czech government faced a criticism for their late step in into the situation. *A similar trend happened with gas prices. When adjusted for purchasing power, residents of Czechia in the second half of 2022 paid the highest amount for gas out of all EU countries.*[5]

[3] https://www.bruegel.org/analysis/european-union-russia-energy-divorce-state-play
[4] https://www.novinky.cz/clanek/ekonomika-energie-pomoc-a-ceny-40406258
[5] https://www.expats.cz/czech-news/article/people-in-czechia-paid-the-most-for-energy-in-the-second-half-of-last-year

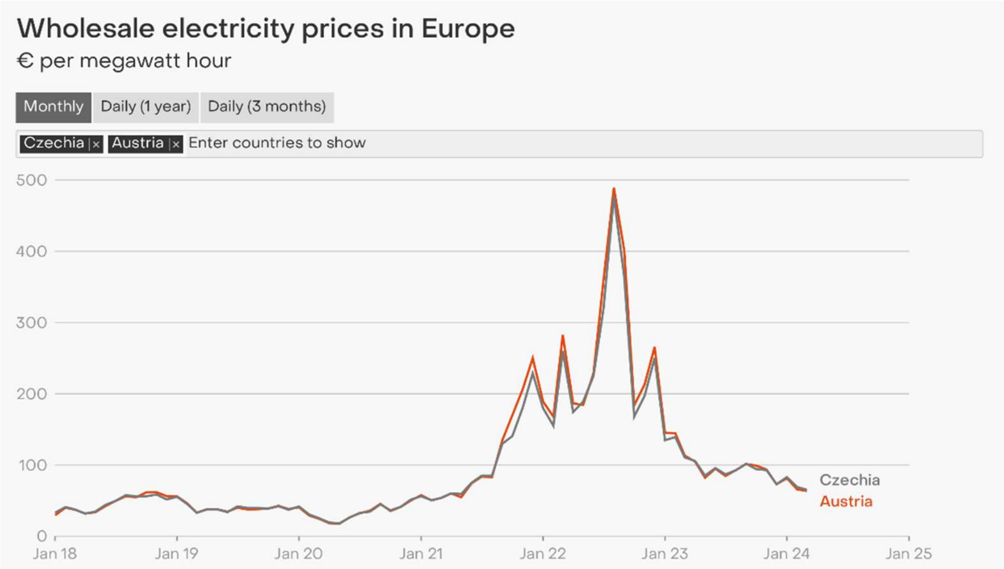

Figure 9 - wholesale electricity prices in Europe

Green Deal – 100% renewable

Green deal is a hot topic of today's politics in the European Union and since it's trying to make Europe as carbon neutral as possible, it faces many challenges that it needs to overcome, while not damaging its economy during the process. Problems and challenges will impact broader spectrum of areas like climate, energy, agriculture, transport, environment etc. Since EU is large and countries have a different conditions like climate of economical state, it's going to take a lot of effort to meet criteria set to make EU carbon neutral by 2050. *The energy sector is responsible for more than 75% of the EU's greenhouse gas emissions. Increasing the share of renewable energy across the different sectors of the economy is therefore a key building block to reaching the goal of reducing net greenhouse gas emissions by at least 55% by 2030 and becoming a climate-neutral continent by 2050.* So far EU has met its criteria which were set for year 2020.

2020 target

EU's target for 2020 was to increase the share of renewable energy to at least 20% of consumption. According to Eurostat's renewable energy statistics from January 2022, the EU overachieved its target in 2020 with a 22% share of gross final energy consumption from renewable sources. The definitive figures, reported by the EU countries under the Regulation of the Governance of the Energy Union in April 2022, confirmed the conclusions of Eurostat and revealed that in 2020, the EU reached a share of 22.1% of renewable energy in gross final energy consumption, thus exceeding the 20% share aimed at under the 2009 Renewable Energy Directive.

2030 target

Building on the 20% target for 2020, the recast Renewable Energy Directive 2018/2001/EU established a new binding renewable energy target for the EU for 2030 of at least 32%, with a clause for a possible upwards revision by 2023. The revised Renewable Energy Directive EU/2023/2413 raises the EU's binding renewable target for 2030 to a minimum of 42.5%, up from the previous 32% target, with the aspiration to reach 45%. It means almost doubling the existing share of renewable energy in the EU. The directive entered into force in all EU countries on 20 November 2023.[6]

2050 target

Pursuit of climate neutrality in EU begun in 2015, when 195 countries (whole EU being a part of it) signed a worldwide Paris agreement. By following this agreement, the world is going to achieve long term goal of reducing global greenhouse gas emission and to hold global temperature increase bellow 2°C above pre-industrial levels and pursue efforts to limit it to 1.5 °C above pre-industrial levels. All that while providing financing to a developing country, which they can use to tackle a climate problem and assessing the progress globally every 5 years and globally assessing the progress every 5 years. *Pre-industrial levels refer to the global atmospheric conditions, particularly concerning greenhouse gas (GHG) concentrations and global temperatures, that existed before the widespread impact of industrialisation. This period is generally considered to be before the year 1750, a time before the extensive burning of fossil fuels began to significantly increase the levels of CO2 and other GHGs in the atmosphere.* [7] Paris agreement gave an opening for a Green Deal, which is supposed to make Europe a first climate neutral continent in the world. Both Austria and Czechia signed those deal and intend to fulfil them.

Electric vehicles and renewable energy

Electric vehicles (EVs) are one of the most promising technologies for reducing emissions in global transportation, but the benefits they bring depend on the provenance of the power they run on. Today, too few EVs are powered by renewable energy. For them to be a truly green option, this has to change. The EV revolution is upon us. According to the International Energy Agency (IEA), the number of electricity-powered passenger vehicles on the world's roads could surpass 250 million by 2030, while the International Renewable Energy Agency (IRENA) estimates that electric buses and other mass transit vehicles could number well over 10 million. Transport produces around one-fifth of global emissions. EVs need anywhere between 24 and 50kWh of electricity to travel 100 miles, and this electricity comes from the grid. With a US Department of Energy study showing that increased electrification will boost national consumption by as much as 38% by 2050, in large part because of electric vehicles, in some cases, EVs could result in substantial greenhouse gas (GHG) emissions or even help extend the life of fossil fuels, if charged primarily with fossil fuel-generated power. Essentially, unless the electricity that powers EVs is clean, EVs can never be a fully green option. It isn't only the juice that powers the vehicles' batteries that's important. Half of the lifecycle emissions from the lithium batteries in EVs come from the electricity used to

[6] https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-targets_en

[7] https://www.senken.io/glossary/pre-industrial-levels

assemble and manufacture them, which means that the electricity mix at OEM facilities is also a key part of the equation. The climate benefit of EVs, therefore, doesn't just depend on how green the electricity used to charge their battery is, but also on the carbon intensity of the electricity used to make that battery – creating yet another imperative for EV manufacturers to switch to renewable energy. The rise in the adoption of EVs can also drive the growth of renewable energy in other ways. Private cars spend 95% of their time parked, and energy planners are looking at ways to utilize this dead time to solve one of the biggest problems for scaling up renewable grids: stability. The technology to make it happen is called vehicle-to-grid (V2G). With good planning and the right infrastructure, EVs can reduce emissions, replace polluting vehicles, boost the roll-out of renewable energy infrastructure, and, when parked up and plugged in, act as battery banks, stabilizing electric grids powered by renewable solar energy.[8]

Vehicle–to–grid (V2G) and Vehicle – to – everything (V2X)

Vehicle-to-grid, or V2G for short, is a technology that enables energy to be pushed back to the power grid from the battery of an electric vehicle (EV). With V2G technology, an EV battery can be discharged based on different signals – such as energy production or consumption nearby. V2G technology powers bi-directional charging, which makes it possible to charge the EV battery and take the energy stored in the car's battery and push it back to the power grid. While bi-directional charging and V2G are often used synonymously, there is a slight difference between the two. While bi-directional charging means two-way charging (charging and discharging), V2G technology only enables the flow of the energy from the car's battery back to the grid. Besides V2G, there is another abbreviation often mentioned in relation to bi-directional charging - V2X. V2X means vehicle-to-everything. It includes many different use cases, such as vehicle-to-home (V2H), vehicle-to-building (V2B) and vehicle-to-load (V2L) services.[9]

New registration of EV in Europe (2022)

Considerable progress in the uptake of electric cars and vans in the EU was made in 2022, with 21.6% of new car registrations being electric vehicles. Totalling close to two million electric car registrations in one year, up from 1,74 million in 2021. The number of electric vans on European roads also continued to grow, reaching a share of 5.5% of new registrations in 2022.

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[8] https://www.atlasrenewableenergy.com/news-and-insights/electric-vehicles-and-renewable-energy-a-perfect-match

[9] https://www.virta.global/vehicle-to-grid-v2g

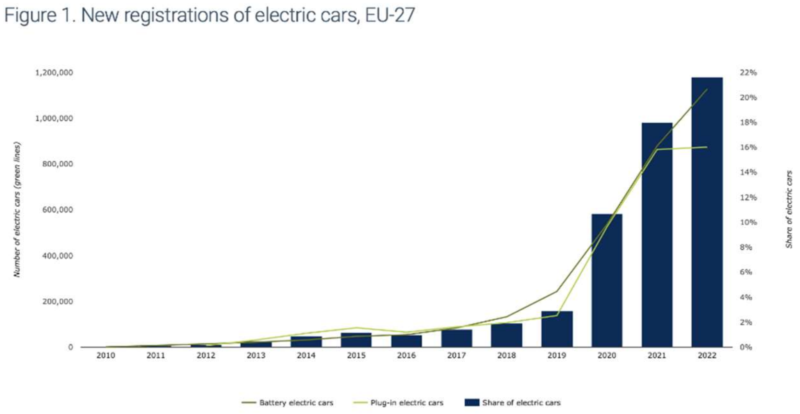

Figure 10 - New registration of electric cars for EU-27

In 2022, the share of electric vehicles in new car registrations increased in almost all countries (EU-27, Iceland, Norway) compared with 2021. The highest shares were found in Norway (89%), Sweden (58%) and Iceland (56%). In four European countries, the percentage of EV registrations remained lower than 5% of the total fleet (Cyprus, Poland, Czechia, and Slovakia). Austria's share of newly registered Electric vehicles in 2022 was over 20%.[10]

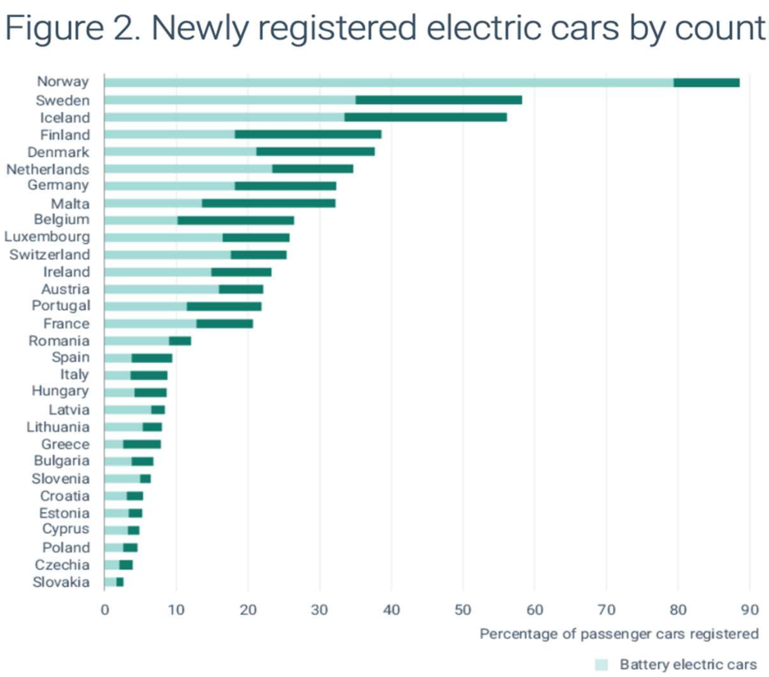

Figure 11 - Newly registered EVs by country

[10] https://www.eea.europa.eu/en/analysis/indicators/new-registrations-of-electric-vehicles?activeAccordion=546a7c35-9188-4d23-94ee-005d97c26f2b

European policy – Role of EU

Even though countries of EU use their own infrastructure to produce electricity, such as Nuclear powerplant and renewable energy, electricity market was highly affected due to use of fossil fuels used in electricity generation. *Russia's full-scale invasion of Ukraine caused severe spikes in energy prices across the EU in 2022. To avoid price shocks in the future, the EU is reshaping its electricity market*. New changes should make electricity prices less dependent on the prices of fossil fuels. Changes aim to ensure:

- Better Protection for consumer

This will open new options for citizens, and it will offer them: increased availability of fixed-price and fixed-term contracts. Flexibility to choose dynamic pricing, with multiple or combined contracts possible. Clearer information before signing.

- More stability for companies

Businesses will have more stable prices thanks to a long-term contract (such as power purchase agreements whereby the power generator agrees to sell energy directly to energy consumers at a certain price. Investments in new power generating facilities based on wind energy, solar energy, geothermal energy, hydropower (without reservoir) and nuclear energy will be made in the form of two-way contracts for difference. (CfDs). On the one hand, this secures a minimum return on such investments and on the other, it prevents excessive costs in the event of another crisis.

- Increased green electricity.

New rules will also make it easier to integrate renewables into the system. Moreover, renewable generation will be easier to predict (through new transparency obligations for system operators and enhanced ability to monitor the energy market). This will make it possible to both keep prices under control and meet ambitious climate targets that the EU set in the Fit for 55 package. Fit for 55 package aims to reduce emissions in countries of the EU by a minimum 55% and all of that should be achieved by 2030. It is even made as a legal obligation, and it should be a first step to achieve carbon neutrality by 2050.

This reform was introduced on 14. March 2023 more than one year after Russia began its aggression on Ukraine. Files had already been voted agreed on by EU parliament in April 2024 and they now need to be formally adopted by EU council. [11]

[11] https://www.consilium.europa.eu/en/policies/electricity-market-reform/

Conclusion

It is apparent that the future European energy system will be much less homogenous than it used to be. Generation capacities will be located much further from where consumption is located. At the same time generation will also be less consistent and less predictable. Exchanging electricity internationally helps to alleviate these issues. Thereby socio-economic welfare is generated, and emission goals can be reached. Integral to this exchange is the physical infrastructure which is the pan-European power grid. We urgently must advance the expansion of the grid.

Whatever it may be: Russia, China or populists, the EU´s unity will have to prepare itself against future challenges which could affect international relationships and therefore might slow down building of a better grid or achieving its long-term goals such as climate neutrality. European Union as an imagination of a perfect continent still lies a long way ahead and we need to be ready.

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