Fonds européen de développement régional (FEDER)
Europäischer Fonds für regionale Entwicklung (EFRE)

Roadmap for the Trinational Upper Rhine Metropolitan Region (TMO/RMT)

Project Lead: Prof. Dr. Barbara Koch, University of Freiburg

Table of Contents

I. Introduction

Chapter 1. A Regional Governance Approach to the Energy Transition with Key Concepts, Technologies and Tools: EU Policy Context and Literature Review

Resource-efficient and climate-neutral energy systems are at the core of a defossilized society and economy in line with international and EU policy goals. The energy sector accounts for more than 75% of the EU's greenhouse gas (GHG) emissions. Through the legislative package "Clean Energy for all Europeans" and the thus revised energy policy framework, the European Union aims to transform the EU energy sector towards sustainability and emission neutrality by 2050 in a socially just manner. There are revised provisions for a net GHG emission reduction target of at least 55% below 1990 levels by 2030, an energy efficiency target of 32.5%, a renewable energy target of 32% (both by 2030 from a 1990 baseline), more rights for prosumers, a smarter and more efficient electricity market which helps increase the security of supply by integrating renewable energy sources (RES), managing risks and improving cross-border cooperation (European Commission, 2018a, 2018b, 2019, 2022a). The EU Green Deal with the 1 trillion Euro Investment Plan for Europe for sustainable investments will help the EU to reach these goals, while also supporting regions still dependent on fossil fuel (mostly coal) production and helping with the recovery from the COVID-19 pandemic. One third of the 1.8 trillion Euro investments from the NextGenerationEU Recovery Plan and the EU seven-year budget will finance the European Green Deal (European Commission, 2022b).

According to the latest "State of the Energy Union" report (European Commission, 2021), the main current priorities are making the EU more energy efficient, less dependent on fossil fuels[1] and more resilient, while also mitigating climate change and providing clean and affordable energy to end-users. To this end, there is a need to fundamentally change existing energy consumption and production patterns, including addressing hard-to-decarbonise sectors, for instance through renewable hydrogen in line with the EU hydrogen strategy.[2] In the framework of the 2021 Recovery and Resilience Facility (RRF), almost all EU member states are using RRF funds to invest in renewable energy, building renovation and sustainable mobility. Notably, buildings account for around 40% of the EU's total energy consumption and 36% of the GHG emissions from the energy sector, whereas currently 75% of the building stock is categorised as energy inefficient. Other priorities are decoupling economic growth from energy consumption, improving market coupling for a common EU trading platform for electricity,[3] promoting renewable energy communities and citizen energy communities as well as their collaboration with distribution system operators (DSOs), ensuring cybersecurity of cross-border electricity flows, phasing out fossil fuel subsidies, and streamlining processes to address administrative and investment barriers to the energy transition. Moreover, the European Commission proposed a new target of 40% of renewables in the EU gross final energy consumption by 2030 (European Commission, 2021).

[1] The net energy import dependency in the EU reached 60,6% in 2019, which was the highest level for the past 30 years (European Commission, 2021).

[2] One key objective is to deliver 40 GW capacity for electrolysers producing renewable hydrogen by 2030 (European Commission, 2021).

[3] Market coupling in the context of the European Union Internal Electricity Market (IEM) refers to the "integration of two or more electricity markets from different areas through an implicit cross-border allocation mechanism" (https://www.emissions-euets.com/internal-electricity-market-glossary/481-market-coupling). The goal is to form an interconnected European electricity market for electricity by linking control areas and market areas, in order to harmonise electricity exchanges and to reduce price differences. Implementing market coupling across all EU internal borders is considered to generate significant welfare benefits and to reduce the need for back-up capacities (fossil fuel plants) thus reducing GHG emissions (European Commission, 2021).

Ultimately, however, these EU-wide policies and the corresponding national policies are implemented at the regional and local levels of governance. These are, in fact, the levels of governance closest to citizens and in this way best able to tailor overarching policies to territorial specificities (Gerbelová et al., 2021; European Committee of the Regions, 2019). The European Commission has highlighted the fact that cities and their regions are key sites for the transition to a decarbonised Europe, and that the local and regional levels possess a far greater ability to adopt and translate into action ambitious low-carbon energy goals (European Commission, 2020). The "Clean Energy for all Europeans" legislative package also highlights the potential of a regional approach to the energy transition. It promotes both regional energy systems with integrated energy markets and regional solutions with viable capacity mechanisms to ensure security of supply, energy efficiency and cost-effectiveness in the context of decentralised generation from RES (European Commission, 2019).

According to the International Energy Agency (IEA, 2019), the cross-border integration of power systems is a key solution for increasing renewable energy (RE) shares and security of supply in a cost-effective manner. The increased diversity of RES and load profiles extends security margins, requiring fewer resources to satisfy on-peak demands and enabling a reserve sharing management. In addition, larger areas can better cope with the intermittent behaviour of RES. The ideal cross-border electricity system requires effective collaboration between system operators, long-term planning, and the involvement of regional institutions. Challenges are related to non-harmonised profit sharing, lack of coordination increasing the blackout risk, and the management of loop or transit flows particularly found in regions with high RES shares. These challenges could be addressed by increasing real-time coordination through governing market frameworks and institutions, building more stable energy systems and improving structures for cross-border energy trading (IEA, 2019).

It is therefore important to consider both regional and cross-border approaches to the energy transition. The research and innovation work conducted in the RES-TMO project aims to contribute to the implementation of the energy transition goals of the cross-border Upper Rhine Region, including parts of the Grand Est region (France), Southern Palatinate and Baden (Germany), and Northwest Switzerland. The main challenge in this regard is that these countries feature different social and regulatory systems. Their energy mixes, approaches to renewables and decarbonisation plans also differ. At the same time, our results indicate that transborder cooperation could effectively accelerate the transition to renewables-based energy systems. Other objectives of the RES-TMO project are the evaluation of the renewable energy potentials and an analysis of energy decarbonisation pathways for the TMO region. At the level of the Upper Rhine region, in the framework of the Treaty of Aachen[4] and the Fessenheim Territory Project[5], the Franco-German Council of Ministers agreed on the joint further development of the area around the Fessenheim nuclear power plant (NPP) after its decommissioning in 2020. One main objective is transforming the area into a pilot region − greenhouse gas (GHG) emission-free, innovative economic region - with a sustainable energy and transport concept based on a renewable energy supply, while at the same time promoting local economic value and job creation. The findings of the RES-TMO project can be used to

[4] Vertrag von Aachen v. 22.01.2019: https://www.bundesregierung.de/resource/blob/997532/1570126/fe6f6dd0ab3f06740e9c693849b72077/2019-01-19-vertrag-von-aachen-data.pdf?download=1

[5] Projet de territoire de Fessenheim / Raumprojekt Fessenheim: http://www.haut-rhin.gouv.fr/Politiques-publiques/Avenir-du-territoire-de-Fessenheim/Zukunft-des-Raumes-Fessenheim-Avenir-du-territoire-de-Fessenheim

contribute to this process, in the framework of the sustainable energy transformation of the broader Upper Rhine region.

Numerous studies have dealt with the **implementation process of the energy transition at regional and local governance levels**, looking specifically at the transition governance, key technologies, concepts and tools, as well as the key factors for success. A recent study (Goers et al., 2021) identifying the strengths, weaknesses, opportunities and threats (SWOT) of renewable energy deployment of Regional Leaders Summit (RLS) regions came to the conclusion that regional governments, in the larger framework of national and supranational policies, play a key role in the transformation of global energy systems by enabling regions to develop partially distributed, decentralised renewables-based energy systems with embedded energy storage, demand side management and smart technologies. In this process, political decision-makers should take into account regional specificities, market conditions and possible effects on society and economy, and broad stakeholder participation and cooperation should be fostered. While internal factors such as RE potentials and sound legal frameworks can strengthen the role of RE in regional energy transitions, the path dependency on fossil fuels, which are still being subsidised, and related energy-intensive industrial structures, are identified as weaknesses. As regards external factors, the deployment of RE can lead to opportunities related to job creation and green economy, on top of climate action, while factors such as the lack of social acceptance and RE volatility can threaten the importance of RE in the implementation of regional energy transitions. Moreover, alternative approaches such as green economy, decoupling economic growth from fossil energy consumption, and related regional strategies are needed in order to decarbonise and defossilize society and economy. To measure and monitor progress, high-quality data on all aspects of the energy transition play a crucial role, as it also became clear in the research and development conducted within the RES-TMO project. Based on these data and reliable indicators (e.g. from OECD recommendations), regional governments can measure progress against the objectives of their green economy strategies (Goers et al., 2021).

Internal Strengths	Internal Weaknesses
• Usage of RE for electricity, heat and fuels • RE potentials • Sound legal RE frameworks and instruments • RE research and development • Expertise in RE conversion and storage	• Dependence on fossil energy • Energy-intensive industrial structures (which require stable energy supply historically supported by fossil fuels) • Limited grid access for RE
External Opportunities	**External Threats**
• Green economy • Employment (green jobs) • Economic growth • Contributions to climate protection • Technological innovation and Industry 4.0	• Demographic developments • Lack of social acceptance • Volatility of RE resources

RE: renewable energy.

Figure 1.1: SWOT analysis for the support of renewable energy in Regional Leaders' Summit (RLS) regions' energy transitions (Goers et al., 2021).

In a study (Cooke, 2011) analysing the interaction between regional and national drivers for the transition towards climate neutral energy systems, transition regions are defined as "sub-national territories, usually with some degree of devolved governance in the fields of innovation, economic development and energy that, for reasons to be demonstrated, act as regional ‘lighthouses’ for eco-innovation both to other regions and countries.” It is found that such regions may be either stimulated or hindered in their transition by the dominant (national) socio-technical systems. It is also found that smaller local administrations can play an important role in changing the national energy mix, as shown by a case study of Denmark where there was a shift to decentralised combined heat and power plants (CHP), and that public procurement can help to “develop ‘strategic niches’ and stimulating eco-innovation by ‘preadaptation’ or seeking ‘relatedness’ and the ‘adjacent possible’ by stimulating regional ‘path interdependencies’” (Cooke, 2011).

Another study, focusing on a governance mechanism to ensure resilience of electricity systems, including generation, transmission and distribution, of the Austrian Climate and Energy Model (CEM) regions comes to the conclusions that a multi-risk governance perspective could strengthen “resilience[6] of urban socio-economic systems against electricity blackouts” and that the implementation of such a process could benefit from participatory governance. The latter is based on a process which involves stakeholders and includes the design, selection, implementation and evaluation of strategies for disaster risk reduction. Importantly, the related case studies show that CEM inhabitants were ready to pay extra for electricity coming from RES and from their regions, which is in line with our findings for the Upper Rhine region, TMO (WP4). Moreover, it is observed that inhabitants and stakeholders would also be ready to participate in decision-making processes on energy transition to address risks and increase regional resilience, e.g. in the context of regional energy groups. It is also highlighted that regional resilience requires the integration of knowledge that is interdisciplinary, comes from different stakeholders and from community residents themselves, including a “better understanding of perspectives, interests and needs of different stakeholders from the private and public sector” (Komendantova, 2018).

Lutz et al. (2017) analysed the driving factors for the regional implementation of RE, based on 18 selected study regions from the German 100EE-regions-network. They found that comprehensive and well-structured planning processes, including effective process management and carefully chosen milestones, can make a considerable difference in the transition governance for a successful regional and local RE implementation. For instance, regions using integrated climate protection programs (ICPP) seemed better prepared to deal with national climate change mitigation policies. Second, strong engagement in formal networks is found as very beneficial, particularly when the networks provide opportunities for intensive exchange of knowledge and expertise between regional actors and experts, as this may help to successfully deal with the complex challenges around RE implementation. Another success factor found is related to strategies for regions for combining RE funding from different sources, including community energy initiatives (CEI) and public funding (Lutz et al., 2017).

Müller et al. (2011) look into energy autarky, which is conceptualised as “a situation in which the energy services used for sustaining local consumption, local production and the export of goods and services are derived from locally renewable energy resources” (RES). They find that the implementation of higher levels of energy autarky requires increasing energy efficiency, using regional RES potentials and relying on decentralised energy systems. In practice, it also requires local administrators and civil society actors to develop projects, ensure their acceptance and support by the local population and collaborate with relevant actors. Sustainable regional development through energy autarky may provide an “overriding vision or framework, within which renewable energy innovation can be positioned, and hence social

[6] From an engineering perspective, resilience is defined as “the ability of a system to return to a steady-state after a disturbance” (Davoudi, 2012). From an ecological perspective it is referred to the “ability of a system to absorb changes” (Holling, 1993) and continue functioning.

acceptance of renewable energy innovations may be increased". It could also inspire the further development of the European Energy Award (EEA) and the communities that are already advanced in the EEA "to take their energy policy to the next level" (Müller et al., 2011).

Finally, a study proposing a governance approach to regional energy transition includes five key clusters: structural characteristics of the regional network, regional network composition, actor characteristics, regional network governance, and external factors. The framework is applied to a case study, in order to improve the understanding of governance of regional energy transition. Success factors are linked to structural characteristics of the network (e.g. regional/local government taking an important role as intermediary or facilitator), regional governance (e.g. the importance of a leading actor with formal mandate to govern) and actor characteristics (e.g. municipalities following up on transition governance). Moreover, external factors such as dependency on national government in setting policy priorities and regional political and administrative priority formulation were also found as important, as they limited progress in the agenda-setting for regional energy transition. The results also show that the region's main city is involved in most of the key regional projects, however public officials of these cities are not always keen on engaging in regional collaboration, in contrast to those in peripheral areas of the region (Hoppe & Miedema, 2020).

Regarding the **main technical challenges, technologies, concepts and tools** for the implementation of the energy transition towards RES-based resilient energy systems, which apply to the regional and local levels, there are also recent studies that are relevant for our project findings. Since the main emission reduction strategy in the European final energy consumption is dependent on the development and upscaling of variable RES, such as wind and solar, a key issue remains balancing energy supply and demand to ensure electricity grid stability (frequency and voltage stability) at all times. Given the strong seasonal fluctuations in solar and wind energy feed-in, i.e. their intermittent nature, there is a high demand for flexibility mechanisms for the electricity grids, including short and long-term energy storage technologies (Brown et al., 2018). Viable solutions for system flexibility found in many studies include not only the development of energy storage technologies and back-up generation systems not reliant on fossil fuels, such as CHP-powered by renewable hydrogen, but also the extension of grid capacities, the coupling of the power sector with the heat and transport sectors, demand side management and digitalization (Gils et al., 2017; Victoria et al., 2019; Zimm et al., 2019).

There are various technologies for electricity storage including electric batteries and hydrogen-based storage. In addition, the development of adequate grid capacities supports the decentralised RE penetration, reduces grid bottlenecks due to the closure of nuclear power plants (NPPs) and dampens the effects that their decommissioning has had on the industrialised south (of Germany), especially given the fact that most offshore and onshore wind energy potential and development happens in the northern part (Schiffer et al., 2018). Finally, demand side management and digitalization increase the flexibility of the energy system by helping convert its behaviour into "demand follows supply" and bringing about valuable energy efficiency savings (Zimm et al., 2019). The technologies needed for long-term energy storage are techniques for converting energy into hydrogen, gas or fuel and can be used in various ways, e.g.: 1) Hydrogen production by electrolysis (for use in the gas grid, as a fuel for electricity and heat, or together with fuel cells and electric motors); 2) Conversion of synthetic methane; 3) Conversion of hydrogen (H2) into liquid fuels (Henning & Palzer, 2015). It has been found that using hydrogen directly for heating might be too costly and inefficient and thus, no solution for avoiding challenging renovation of buildings or retrofitting of renewable heating systems, but it could help to decarbonise hard-to-abate sectors. In the medium and long-term, energy efficiency options should be used to optimise heat decarbonisation processes because they "can immediately deliver real carbon savings, while accommodating a growing share of renewable sources" (Avere et al., 2020).

To achieve carbon neutrality, one important requirement is to move the energy transition beyond the power sector to include the industry, transport, and residential sectors (including heating), which constitute the next three biggest emitters after electricity in Germany and where mitigation efforts have been far less concentrated (UBA, 2020; Schiffer et al., 2018; Chen C. et al., 2019). Although the German and French energy systems have different structures in terms of energy generation and consumption, one common aspect is the fact that the transport sector is a top CO2 emitter in both (IEA, 2020). In its current form, mobility contributes to approx. 30% of national harmful CO2 emissions in France and approx. 20% in Germany. Electric vehicles constitute one solution and a second solution could be using hydrogen with fuel cells or biofuel blends for the mobility sector (Zimm et al., 2019).

Another key issue is the deep decarbonization of the industrial sector. Energy consumption in the industrial sector is about 3200 TWh per year with a varying average share of 26% of total EU consumption. Germany and France have the highest industrial energy consumption in the EU (Papapetrou et al., 2018). It has been found that industrial decarbonization pathways require a highly focused regional approach because sectoral costs and benefits, local resources like RES and political circumstances are generally region-specific (Bataille et al., 2018). Moreover, it has been shown that the decommissioning of nuclear, oil, coal and other conventional power plants due to the end of their technical lifetime presents great opportunities for repowering Europe's infrastructure with low CO2 technologies, as well as opportunities for oil and gas-fired capacities to shift to carbon neutral fuels (Farfan & Breyer, 2017).

In Germany, the share of renewables in 2019 was 42.1% in the electricity sector, 14.5% in the heating sector, and 5.6% in the transport sector (UBA, 2020a). The share of renewables in the gross final energy consumption, including electricity, heating and transport, increased to about 17.1% in 2019, from which 41.5% were from wind onshore, 10.1% from wind offshore, 19.5% from PV, 8.3% from hydropower, 19.5% from biomass (including solid and liquid biomass, biogas, biomethane, landfill and sewage biogenic waste) and 0.1% from geothermal sources (UBA, 2020a). The entire energy sector accounted for ca. 83.9% (2018) of the total GHG emissions, which include stationary and mobile emission sources, fugitive emissions from fuels, and the energy emissions from industry (UBA, 2020c). The Climate Protection Act (Klimaschutzgesetz, KSG) from 2019 sets binding targets for GHG emission reductions of at least 35% by 2020 and 55% by 2030 (both from a 1990 baseline). It also states Germany's long-term goal to pursue GHG neutrality by 2050 (UBA, 2020b, 2020c, 2020d). More recently new rules were introduced and as of August 31, 2021, GHG neutrality should be reached by 2045 and new GHG emission reduction targets are: 65% for 2030 and 88% for 2040 from 1990 levels (Bundesregierung, n.d.). The now prevailing narrative for a low-carbon, renewables-based and nuclear-free energy supply was translated into policy early on (e.g. feed-in tariff 1990; first EEG in 2000, etc.). However, fundamental divides remain with regard to the transition implementation, with tensions between the long-term goals and the more short-term supply security and reasonability of electricity prices (Leipprand, Flachsland & Pahle, 2017). It has been shown that Germany can fully replace its NPPs with RES-based generation by 2025, if related challenges are solved, i.e. grid expansion and provision of balancing power (Lechtenböhmer & Samadi, 2013).

In France, the share of electricity from RES was 23% in 2019, 10% of which came from wind, 2.5% from solar Photovoltaic (PV) and 13.2% from hydropower. The goal is to reach 40% renewables in electricity and 38% in final heat consumption by 2030 (IEA, 2021). Renewables accounted for 17.2% of gross final energy consumption in 2019, with an increase of 8% since 2005. Under the EU Renewable Energy Directive (national transposition), France has a 2020 target for 23% renewable energy in total energy consumption, from which 33% in the heating and cooling sector, 27% in electricity and 15% in transport (IEA, 2021). Introduced by the 2015 law on energy transition for green growth ("Loi relative à la transition énergétique pour la croissance verte"), the Multi-Year Energy Program sets out the priorities for government action in the field of energy and is coupled to the National Low Carbon Strategy ("Stratégie nationale bas carbone" SNBC) describing France's climate change mitigation roadmap. The closure of the last coal-fired power plants was expected by 2022, but such power plants were actually authorised to produce electricity in January and February 2022 due to power outage fears despite the previously set target (Serafino, 2022). An interesting fact is that "under the Hydrocarbons Law of 2017, no exploration and production will be permitted beyond 2040 and no new production permits have been issued since the law entered into force. With this, France has become one of the first countries to completely ban gas and oil exploration on the national territory, although it is mainly a symbolic measure, as proven and recoverable deposits in mainland France are almost nonexistent" (IEA, 2021). The renewable electricity target for 2028 aims for a share of 33-36%, while the share of nuclear electricity is to be reduced to 50% by 2035 (IEA, 2021). This involves the shutdown of 14 nuclear reactors by 2035 and the option of building new NPPs is still under study. However, the SNBC roadmap is not being fully respected since the first carbon budget, between 2014 and 2017, was exceeded by 3.5% due to milder winters and shutdown of some NPP units. The increase in GHG emissions is mainly related to two sectors: the energy conversion sector (electricity production) and the residential sector, and to a lesser extent to the transport sector (increase in emissions from gasoline-powered vehicles).

In 2019, the share of renewable energy in Switzerland's final energy consumption reached 24%, from which 23% was in the heating sector and 58% in electricity. Hydroelectric power accounted for around 57% of the electricity production. The other renewables combined – solar, biomass, biogas, wind, and waste-to-energy – provided 6.2% of total electricity generation. Under the 2015 Paris Agreement, Switzerland has committed to halving its GHG emissions by 2030 compared to 1990 levels. Furthermore, in 2019 the Swiss Federal Council also adopted a carbon neutrality goal for the year 2050 (BFE, 2020). A modelling study of the Swiss energy transition found that increased power market integration of Switzerland with Europe can ensure least cost electricity generation and strengthen Switzerland's role as a transit and storage hub (Weiss et al., 2021). Another study identified thermal storage as the most important technology in the Swiss storage mix for low carbon energy scenarios, as it can ensure up to 50% of storage needs and be combined with electrical heat pumps, vehicle to grid and synthetic fuel storage (Limpens et al., 2019).

In reference to the project study area, a downward trend in GHG emissions can be observed looking at the energy demand side in the Upper Rhine region. However, this decrease is not sufficient to achieve the national and regional climate targets, and in the entire cross-border area, 2016 emissions amounted to approximately 9 tons per inhabitant, including notably energy-related emissions (TRION-climate, 2019).

If the power system is coupled with the heating and transport sectors (sector coupling), deeper GHG emission reductions can be achieved. Sector coupling can provide significant additional storage in two ways: 1) electricity can be stored in batteries of electric vehicles (EV), and 2) large short and long-term capacities of thermal energy storage can become available to balance the significant seasonal variations in heat demand and both solutions can be used before large reserve storage capacities are resorted to in future scenarios (Victoria et al., 2019). Electric vehicles will be an indispensable part of the future energy system because, on the one hand, propulsion with combustion engines is three times more energy intensive than that of electric motors (Zimm et al., 2019) and, on the other hand, EVs help smoothen solar energy volatility by charging during the day and discharging throughout the night. In fact, a European fleet of EVs could ease the integration of large capacities of solar energy by providing the service of short-term energy storage through smart charging and discharging into the grid (Victoria et al., 2019).

Demand side management, digitalization and smart systems can provide indispensable support for RE-based systems (Weigel & Fischedick, 2019) Demand side management and digitalization increase the flexibility of the energy system by helping convert its behaviour into "demand follows supply" and bringing about valuable energy efficiency savings. Despite this fact, demand side management is often neglected in discussions of future energy scenarios even though it has the potential to make the integration of RES considerably easier. Demand side management consists of lowering the energy demand in order to increase flexibility on the supply side by decreasing the demand for the base load and thereby enlarging the energy portfolio (Zimm et al., 2019). Moreover, through implementing behavioural and technological changes, saved energy units need not be produced in the first place or can be used elsewhere instead. Besides, the decrease in energy units on the demand side can be scaled up to much greater energy unit savings on the supply side when considering the conversion losses incurred (i.e. per energy unit produced, converted, and transported) (Zimm et al., 2019). By shifting the magnitude and timing of the electricity demand and in some cases providing other essential reliability services for the energy system, higher penetration of renewables to the grid is made possible (Bowen, 2019). As a matter of fact, there are different strategies that are used to incentivize residential, commercial and industrial consumers to change their demand patterns or allow the system operator to directly control a portion of their load. They include:

- Price response where consumers shift consumption from more expensive periods of high demand to less expensive periods of low demand;
- Peak shaving where consumption during high demand periods is shifted or shed to reduce peak demand, which allows the demand response to offset the need for additional generation capacity;
- Reliability response where demand is shed in order to balance the loss of supply in a contingency event, such as an unplanned outage of a large power plant;
- Regulation response where the system operator continuously monitors and adjusts a consumer's demand to help balance the system's supply and demand (Bowen, 2019).

Digitalization is defined by Weigel et al. (2019) as describing the transformation caused, accelerated, or facilitated by digital applications, which can be hardware or software or both and has the potential to bring about valuable changes to the energy system and even alter the value chain. Smart markets, smart grids, smart metres and smart homes are examples of these applications. One of the aims of digitalization is to support a future energy system where "demand follows supply", according to the Bundesnetzagentur. In addition, many studies have shown that digitalization through machine learning and artificial intelligence (AI) can greatly increase the accuracy of demand, generation and price forecasting, and consequently support the integration of more RES into the grid. The smart metre is a device at the user level whose usage can induce a ripple effect across the entire value chain. It is an indispensable device in smart home applications and offers the possibility to measure energy consumption in real time, track and characterise the consumption of home appliances, and illustrate the information clearly for the average consumer creating transparency and enabling the consumer to make energy saving decisions accordingly. These types of devices also offer flexibility for the consumer and can be controlled remotely and manually or automatically optimised, increasing customer satisfaction (Weigel et al., 2019).

Thus, it is clear that energy transition and decentralised energy systems will need the uptake of digital technologies, as they provide tools (e.g. smart grids, smart metres) for the efficient coordination of a larger and much more complex energy system based on a multitude of renewable energy sources. They can also improve the performance of energy systems, as they allow active participation of consumers in the system and optimised use of renewable energy. Issues that remain to be addressed are related to the interoperability of energy and information systems and ensuring cybersecurity (Duch-Brown & Rossetti, 2020), the latter being addressed in the work package (WP7) of the RES-TMO project.

Finally, scenario analysis is a proven method for decision support under uncertainty that can provide learning opportunities and transformational change. Scenarios can help to explore potential (transformation) pathways and thus can assist to formulate effective decisions to facilitate transformation towards sustainability (Hoolohan et al., 2019). Energy transformation scenarios from various studies have clearly shown that the future energy system is not bound by the borders of any country but transcends beyond them. Issues such as the management of energy surpluses at both local and regional levels, the challenge of matching supply and demand and maintaining power grid (voltage and frequency) balance at all times as well as short and long-term energy storage remain key in debates around the energy transition. For a number of technologies (e.g. long-term storage based on hydrogen), significant capital investments are still required to reach market maturity and financial policy instruments, such as carbon taxes, could be part of the solution. It is also clear that an energy system relying to a large extent on renewable energy and exploiting local/regional potentials requires a multi-service and multi-technology approach with interventions at multiple governance levels, whereas economic and technical efficiency play an essential role. Raw material requirements and the recyclability of certain technologies remain currently major limitations.

II. Summary of the Main Results of the Technical Block

Chapter 2. Work Package 2: Analysis of Renewable Energy Production and Storage Potentials

The work package 2 (WP2) was responsible for three reports related to the RES potential estimation. The first deliverable Report 2.1.1 (Najjar et al., 2022) focused on drawing from the literature to develop the methodology to be used in estimating the RES potentials in the URR and validating the results. The second deliverable (Report 2.1.2) included a study of the grid connection procedure in the three countries and the proximity of the calculated potentials in the first deliverable to the grid components. The third deliverable (Report 2.1.3) included a quantitative study of the results of the first two deliverables. The main findings of the deliverables of WP2 are presented in a condensed way in the next section.

2.1 Analysis and Mapping of Renewable Energy Potentials in the Upper Rhine Region

2.1.1 Defining the Potentials

The first step in calculating the potential of the different RES was to establish what is meant by the word potential and to develop a clear methodology based on the literature.

In fact, five types of RE potentials (theoretical, geographic, technical, economic and feasible) are defined in the literature (Jäger et al., 2016) and can be visualised in the form of a hierarchy as presented in Figure 2.1 below. Moreover, in the following paragraph, the elaborated definition of the potentials is included and adapted from Jäger et al. (2016).

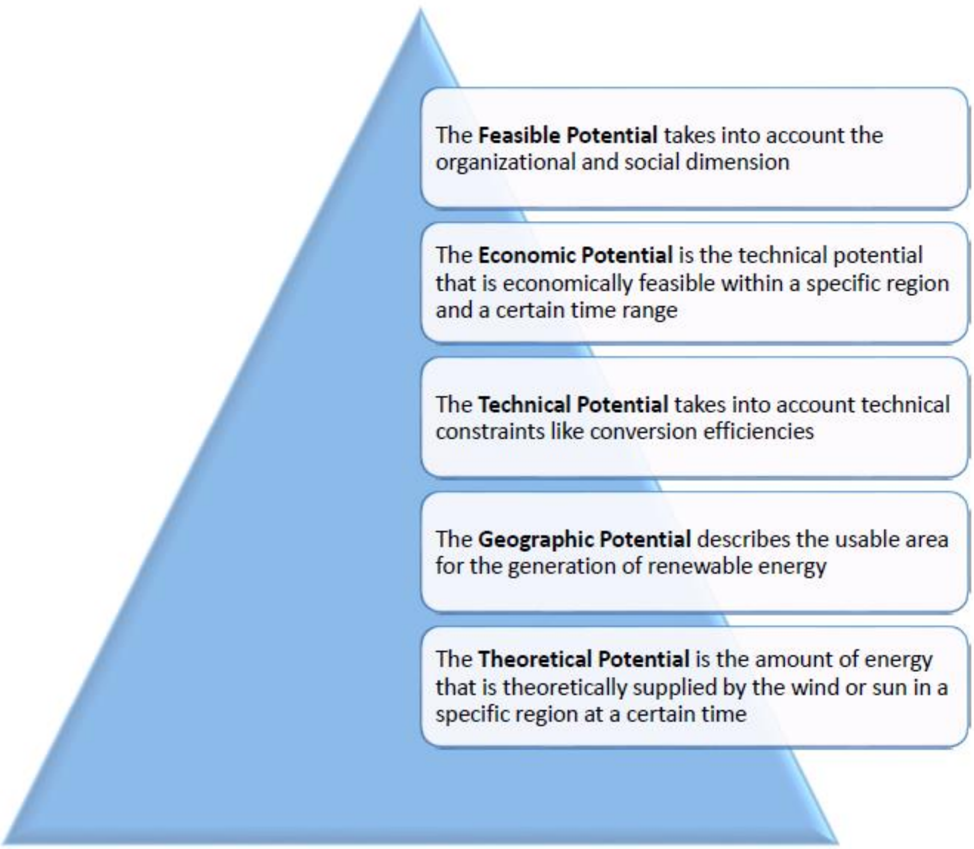


Figure 2.1: The Potential Hierarchy as defined by Jäger et al. (2016)

The theoretical potential is the amount of energy theoretically supplied by wind or sun in a specific region at a certain time. Data on atmospheric conditions, in particular wind speed and solar radiation, and their temporal and spatial resolution are used to calculate this potential. The Upper Rhine region (URR) is characterised by the Rhine valley, enclosed by the mountainous regions of the Vosges in the east and the Black Forest in the west. On the southern edge are the foothills of the Jura in Switzerland. Consequently, the orography of the investigation area is complex which adds to the complexity of modelling e.g. the wind speed. The geographic potential describes the usable area for renewable energy generation taking into account competing land uses such as urban agglomerations, nature protection and applicable legal restrictions. In the URR, considering all regional regulations is a challenging task due to its tri-nationality. Even within the same country (i.e. Germany and Switzerland), the regulations are varying due to the federal structure and legislation. Furthermore, the legal restrictions might differ depending on the energy source (e.g. distance from housing for wind turbines). The geographic potential determines the usable area which is source-dependent and calculated separately for the different sources of renewable energy: wind, rooftop PV and free-range PV. In the case of wind energy and free-range PV potential, the usable area is the area that remains after subtracting the restricted areas for each source such as residential or protected areas and their distance buffers from the total area of the URR. The distance buffer considers the distance that must be respected between the possible renewable energy project sites and the different restricted areas such as cities and roads. Because the geographical potential is closely related to competing land uses, free-range PV can also be divided into two types of potential that require different land-use area types: conventional ground-mounted (GM)-PV and Agricultural (Agro)-PV. The potential of GM-PV and Agro-PV is calculated by dividing the remaining usable area for free-range PV further and accounting for the type of land use pattern.

The technical potential also takes into account technical constraints, such as capacity factors and conversion efficiencies, further limiting the theoretical energy yield. Numerous parameters shape the technical potential. Consequently, the complexity of the applied model to estimate the technical potential heavily determines the accuracy of the resulting potential. The conversion efficiency of PV modules or wind turbines is determined by wind turbine-specific or PV module specific power curves (Huld, 2017 ; Jung & Schindler, 2018). For wind energy, the air density is an additional parameter shaping the energy yield (Jung & Schindler, 2019). Moreover, wake effects, such as turbulence and reduced wind speed, determine the technical wind energy potential. The technical solar PV energy output is influenced by many factors such as the reflectivity of the PV module itself, which is related to the solar angle of incidence, the PV module temperature that depends on the surrounding temperature, and the prevalent surface wind speed (Huld, 2017).

The economic potential is the technical potential that is economically feasible within a specific region and a certain time range. The final stage of the potential hierarchy is the feasible potential, additionally taking into account the organisational and social dimension. This includes for example society’s acceptance of wind turbines in terms of noise pollution or aesthetic landscape aspects, elements addressed in WP4 of the project. These last two potential types were considered beyond the scope of WP2’s work because they are project-specific and can be different from case to case.

2.1.2 Expert Opinions

The next step in establishing a methodology in the first deliverable was to take into consideration expert opinions, regarding the implementation of renewable energy projects, from each of the three countries included in the study. According to one expert, France requires a building permit and that each project be examined on a case to case basis to see if it conforms to the legal regulations specific to its location, such as minimal effect on the environment, landscape, and protected sites as well as respecting the public utility easements and other administrative easements as well. The project should also respect the regulations related to the urbanism, environment, and energy codes. Germany on the other hand, and specifically the state of Baden Württemberg, has clear criteria in the form of a published criteria catalogue when it comes to solar and wind energy and the areas that are suitable for the establishment of a wind or solar farm. The criteria catalogue clearly defines hard restriction areas, which are considered forbidden zones for the propagation of wind and solar projects, and conditionally or partially restricted zones that can be utilised in theory. For solar, they also mention favourable zones such as disadvantaged municipalities (in general where the soil is not suitable for agriculture) where it is encouraged to invest in a PV project. The "disadvantaged areas" according to German law are the acceptable areas for bidding on the development of a Ground Mounted (GM)-PV project. The restrictions and other relevant information for renewable energy are included on the website Energieatlas Baden-Württemberg. (https://www.energieatlas-bw.de/) The other German state included in the study area is Rhineland-Palatinate and it also has certain conditions for wind and solar PV project dissemination that can be found on the Energieagentur Rheinland Pfalz's website (https://www.energieagentur.rlp.de/). When it comes to PV in Switzerland, because of the strict land protection rules, it is very hard to acquire a building permit for a GM-PV or an Agriculture (Agro)-PV project. The difference between the two types is elaborated on at a later stage in WP2's work. Moreover, there are currently no national regulations for feed-in tariffs which makes the most favourable implementation of PV on top of buildings and structures, for the operator's own use. To this day, all PV installations are rooftop installations. The strict land-use regulations also hinder the propagation of wind farms, and in fact there are less than 40 windfarms in the whole of Switzerland. In fact, it was noticed that in the Swiss part of the URR, there is not one GM-PV or Agro-PV installation and only three wind farms (TRION-climate e.V., 2019). Finally, the developed methodology was able to draw upon the expert opinions mentioned in order to define the assumptions presented in the next section.

2.1.3 Assumptions

The last step in developing the potential estimation methodology was defining the assumptions needed to perform the estimation:

Unlike the theoretical and technical potentials, which transcend international boundaries, the tri-nationality of the study area translates into a tri-national regulatory environment, which affects the geographical potential. The geographical potential as defined above should take into consideration the areas that are by regulation classified as inadequate for the dissemination of renewable energy projects. Because the study area comprises three different countries with their own regulatory environment and structure, there is a large disparity in the quality and quantity of publicly available information.

The geographical potential entails the calculation of the usable area, which is source-dependent and calculated separately for the different sources of renewable energy: wind, rooftop PV, and free-range PV. In the case of wind energy and free-range PV potential, the usable area is the area that remains after subtracting the restricted areas for each source such as cities or nature protection areas and their distance buffers from the total area of the URR. The distance buffer simply takes into consideration the distance that must be respected between the possible renewable energy project sites and the different restricted areas such as cities and roads. In the case of rooftop PV, the usable area is the area of the rooftops in the URR. Moreover, because the geographical potential is closely related to competing land uses, taking it a step further, free-land PV can also be divided into two subcategories of potential that require different land-use area types: conventional ground-mounted (GM)-PV and Agricultural (Agro)-PV. The GM-PV and Agro-PV potential is calculated by dividing the remaining usable area for free-range PV further and accounting for the type of land-use pattern.

As stated by the experts above, in Switzerland, there are stringent regulations and no clear guidelines when it comes to wind energy and ground-mounted (GM)-PV projects and in France, the evaluation of renewable energy projects happens on a case-to-case basis. On the other hand, the criteria published by the state of Baden-Württemberg establishes clear and concrete guidelines that can be used to determine the areas where wind or solar dissemination would not be favourable. Therefore, for solar PV and wind energy, the BW criteria catalogues were used in the mapping of the restricted areas and consequently the available usable area. In this way, the methodological framework is more homogeneous and comparable between the three countries.

2.1.4 Methodology

For the estimation of the wind and solar PV potentials, the theoretical, geographical and technical potentials were calculated. The final result obtained was the technical potential per year in TWh for the Upper Rhine Region.

In order to calculate the theoretical potential for wind, data from the wind speed wind shear model (WSWS) developed and described by Jung & Schindler (2017) was used. It is a statistical wind model that uses data from meteorological stations of the national weather services as input for its calculations. Using statistical methods, the long-term median wind speed is mapped on a high-resolution grid of approximately 250m x 250m. The wind speed data sets often contain gaps in certain timeframes or illogical values and so, in order to assure the comparability of the measured data, we used data preparation methods such as gap filling, testing for homogeneity, and de-trending. The result is the yearly and monthly median wind speed value over the entire period. The median wind speeds were then extrapolated to the three chosen hub heights (120m, 140m, & 160m) by using the Hellmann power law. Moreover, the wind power density (WPD) was also calculated and used to determine the areas that are not meteorologically suitable for wind energy projects. The areas with unsuitable WPD as defined by Manwell et al. (2009) were excluded from the usable area as well.

After that, the geographic potential which takes into consideration the restrictions related to orography and competing land use specified by legislation was calculated by determining the restricted areas from the total study area. After that, the restricted areas were subtracted from the total study area and the usable area for wind dissemination was obtained. The Baden-Württemberg criteria catalogue was used as a reference for the calculations of the restricted area.

Finally, the technical potential was calculated. The technical potential minimises the geographic potential by factoring in turbine efficiency in the conversion of the kinetic energy found in the usable area into electrical energy (kWh/year) which is depicted by the Annual Energy Yield (AEY). (Grau et al., 2017) In the literature, Jung (2016) describes in detail the steps to calculate the AEY by using power curves.

For solar PV (rooftop PV, GM-PV, & Agro PV), the theoretical potential was calculated by using the software package PVMAPS to calculate the solar irradiation. PVMAPS take into consideration factors that affect the power generation of solar modules such as: air temperature, wind speed data, and the content of water vapour and aerosol in the atmosphere. Moreover, the software also takes into account terrain elevation, a factor which is important in the determination of clear-sky radiation and the more accurate calculation of the air temperature. (Huld, 2017) The difference between the three solar PV types is the next step of calculating the theoretical potential which entails factoring in the inclination angle of the PV panels. Because of the different roof shapes (slanted or flat) and orientations (south, south east, south west, north, etc.) that limit the flexibility of PV panel placement on roofs, the theoretical potential of rooftop PV had to be calculated separately while free-range PV was considered to be more flexible in terms of panel placement; therefore, the PV panels were assumed to be static and have optimal orientation and inclination angles. Rooftop PV theoretical potential calculation was based on Mainzer et al. (2014) who developed a method for the high resolution estimation of the residential rooftop PV potential in Germany.

The geographical potential entails the calculation of the usable area, and for rooftop PV, the usable area is the area of the rooftops in the URR. In the case of free-range solar PV (Agro-PV and GM-PV), the areas restricted by regulation such as urban agglomerations, biosphere reserves and nature protection areas (determined by the BW criteria catalog for solar PV) were removed as a first step from the total study area and then the usable area (for free-range PV) that remained was divided into two: GM-PV and Agro-PV. Schindele et al. (2020) state that Agro-PV could be placed on areas where agricultural activities take place since the land can be simultaneously used for energy production and agricultural activities. On the other hand, GM-PV's usable area is defined as grasslands that are also used for animal husbandry. The usable area for Agro-PV and GM-PV was determined by the careful analysis of CORINE land cover (CLC) datasets for Europe. This land-cover dataset includes around 44 layers representing different land-cover and land-use classes. After the study of the different datasets and a thorough literature review of the available definition of Agro-PV and GM-PV, we assigned the following land-cover classes: non-irrigated arable land, vineyards, and fruit trees and berry plantations to the Agro-PVs usable area while the land-cover pastures made up the usable area for GM-PV. (EEA et al., 2019) Moreover, by using CLC maps, we also added unsuitable land cover classes to the restricted areas as an additional step.

Finally, the technical potential factors in the conversion efficiency and the performance ratio of the PV panels. These two parameters were considered to be the same as rooftop PV for homogeneity.

For hydropower, our research into the existing literature and regional studies led us to calculate the built-up (already existing) potential instead of the technical potential like in the case of wind and solar PV. Our research determined that experts and energy producers in the three countries attest that the hydropower potential is nearly exhausted in the study region specifically on the Rhine due to the damaging effects hydropower installations have on the ecosystem, which are further elaborated on in our report. In conclusion, the different regional energy experts clearly agree that the regional hydropower potential is mostly exhausted and that the way forward for this RES is through improving the efficiency of the already existing facilities through modernization or the use of micro-hydro installations. These conditions led to the calculated potential relying on the already existing potential of hydro-power plants on the Rhine, the region's largest flowing water body. (Banque des Territoires, 2010, ICPR, 2015, Axpo, 2018 & EnBW, n.d)

In the case of bioenergy, we relied on the extensive research published by the project "Biomass OUI" which studied the energy generation based on biomass potentials of the Upper Rhine Region, ran over the course of three years, and was completed in July 2015. The project was multidisciplinary and relied on the input of various contributors such as economists, engineers, forestry scientists, physicists, biologists, chemists, geographers, and sociologists from prime research institutions across the tri-national region. (Schumacher et al. (Eds.), 2017) Therefore, because the "Biomass OUI" project is a heavily researched and comprehensive project with concrete outputs, the data collected for it by RA1 (research group 1) was used as a basis for the RES-TMO's mapping of the biomass potential of the URR. The researchers in this group completed their task by relying on "statistical data, maps, remote sensing, and Geographical Information System (GIS) modelling". The main aim was to establish "an inventory of the currently available biomass resources and land use in the URR" by determining for each of the three sub-regions, "the total agricultural land area and the proportions of the different cultivated crop plants and their respective yields". (Schumacher et al. (Eds.), 2017) RA1 produced a comprehensive inventory that was used by us to calculate the biomass potential. As a first step, the different sources of biomass were identified in a report published by RA1. These included: agricultural cropping, forestry biomass, and organic residues and waste. (Weber et al., 2014), The specifications of each source are included in our report. The yearly value for each source was calculated in kWh/capita. These values were then multiplied by the number of inhabitants of the URR to obtain an estimate of the biomass current potential per year. It is also important to mention that biofuels were not looked into for Biomass Oui or for this project and that the estimated potential could still increase as new and more advanced technologies emerge.

2.2 Representation of Connection Distances of Previously Unused RE Potentials

In order to develop a methodology for calculating the connection distances of the unused RE potentials calculated in the first deliverable, the general regulatory conditions related to renewable energy and the national grid connection processes of each of the three countries were studied. Expert opinion was also resorted to in order to understand the real-life conditions of connecting to the grid in Germany. The next sections include a comparison between the three countries of the different mentioned topics, and a more detailed description can be read in the original report.

2.2.1 General Structure

In Germany, major players involved in energy generation are facing increasing competition from decentralised energy generation from RES. Moreover, the number of transmission system operators (TSOs) is limited to 4 while the number of distribution system operators (DSOs) is much larger (currently around 900). In France on the other hand, there is one major player, EDF (Electricité de France) which has the largest share and was responsible for 79.8 % of electricity production in the year 2019. Its prominent position can be attributed to the fact that it previously monopolised electricity generation and that it owns and operates all nuclear power plants in France. In addition, the transmission grid is operated exclusively by RTE, Réseau de Transport d'Electricité, the only TSO in France which used to be part of EDF prior to 2012. (Guénaire at al., 2020) In Switzerland, around 80 companies, mostly fully or partially state owned at the cantonal or municipal level, contribute to the generation of electricity. Swissgrid is the national grid company and TSO and there are around 700 DSOs. (Scholl, 2020)

When it comes to electricity generation, renewables (including wind and solar) in the electricity mix accounted for 31.20% in Germany, 10.20% in France, and 3.72% in Switzerland according to the IEA in 2020. While renewables contribute the most to electricity production in Germany and are followed by coal, in France the major energy source of electricity is nuclear followed by hydropower, and in Switzerland the order is reversed as hydropower is followed by nuclear energy. (IEA, n.d.)

2.2.2 Regulatory Conditions

In Germany, the Renewable Energy Sources Act, EEG (Erneuerbare-Energien-Gesetz) has controlled the priority feed-in of renewable energy sources in the grid since it was first introduced in April 2000. The EEG has been revised many times over the years and the latest version found is EEG 2021 as per the Federal Ministry for Justice and Consumer Protection's website. The purpose of the EEG is to synchronise the development of renewable energy technologies with the expansion of the grid and to improve the market integration of RES. (50 Hertz, 2020a)

In France, the French president signed Law No. 2019-1147 of 8 November 2019 regarding Energy and Climate (Loi n° 2019-1147 du 8 novembre 2019 relative à l'énergie et au climat). The law transposed part of the EU "Clean Energy for all Europeans" legislative package which is composed of four directives and four regulations published in the period between June 2018 and June 2019. (Guénaire at al., 2020) This law is supported by several ordinances. The reasons behind this law are to honour the commitments, which France made to the Paris Agreement in 2015. (Boring, 2019)

In Switzerland, the Energy Act (Energiegesetzt, EnG) was completely revised, voted for and passed by the Swiss electorate in May 2017 through a referendum. The Parliament deemed the revision necessary in order to introduce support measures that help to implement the Energy Strategy 2050 in phases. The Energy Strategy 2050 aims to reduce energy consumption, increase energy efficiency and promote renewables. Moreover, support is also given to help hydropower plants cover their production costs. Other amended legislation also helps introduce measures in support of the strategy. Moreover, the Energy Ordinance (Energieverordnung, EnV) regulates among other things the spatial planning in connection with renewable energies, compensation for renovation measures for hydropower plants, the support measures in the energy sector, and international cooperation within the scope of the EnG.

2.2.3 Grid Connection Procedure

In Germany, the grid connection procedure is elaborated in dedicated sections of the EEG in terms of the procedure and rules that regulate the exchange between plant operators and grid operators. Out of the three countries in the study area, Germany is the only country that clearly states in its laws that feed-in priority for renewable energy projects should be given. Notably, Section 12 of the EEG (§ 12) which states that:

"The grid operator is obligated to immediately optimise, boost, and expand the grid in keeping with the most advanced available technology when requested by a renewable energy plant operator interested in feeding in electricity to the grid such that the purchase, transmission, and distribution of electricity from renewable sources is guaranteed. This obligation extends to the grid operators that the plant is directly connected to and upstream grids with higher voltages (110 kV) on the condition that the needed grid upgrade is necessary to guarantee the purchase, transmission and distribution of electricity. The plant operators are entitled to the expansion on the condition that it is economically reasonable." (EEG, 2021)

In France, on the other hand, the connection procedure may vary and depends on the plant's capacity and whether the plant has to be connected to the high or low voltage grid. If the project to be connected has a capacity greater than or equal to 12 MW, then the connection request would be submitted to the French TSO RTE (RTE, n.d.). French DSOs can also process grid connection requests for projects depending on their capacity. Essentially, the general procedural guidelines follow a similar structure. (Enedis, n.d.) There are different steps, some mandatory and some optional, to establishing a grid connection according to the French TSO, RTE.

In Swtitzerland, Swissgrid, the national grid company, must guarantee non-discriminatory network access to third parties. The technical agreement and conditions are set out in contract form between Swissgrid and the electricity producer. (Scholl et al., 2020) In order to connect a project to the grid, the plant operator must sign a Grid Connection Contract (NAV, Netzanschlussvertrag) whose general conditions are stated in the Appendix 2 (Anhang 2). The

“General Conditions for Network Connection to the Swiss Transmission Network " (ABNA) state the framework conditions for system connections to the Swiss transmission network. The systems can be of different types such as generators, storage installations, distribution networks or end users. That the general conditions be met is an important and integral prerequisite to signing a Grid Connection Contract. (Swiss grid, 2017)

2.2.4 The Electricity Grid

The Grid Components

The relevant grid components that are investigated here as parts of the power grid are substations, transformers, and transmission structures. :

1) Substations

Substations are “the points in the power network where transmission lines and distribution feeders are connected together through circuit breakers or switches via bus-bars and transformers. This allows for the control of power flows in the network and general switching operations for maintenance purposes.” (Bayliss & Hardy, 2012, Publisher Summary)
“In the distribution system, transformers typically take medium, or “primary,” voltages measured in the thousands of volts and convert them to secondary voltages—such as 120, 240, or 480 volts—that can be safely delivered to homes and businesses all over the world.” (Bhattacharya, 2017)

2) Transformers

A transformer is a device that transfers electric energy, by either stepping up or down the voltage, between two AC circuits by using electromagnetic induction. (Britannica, 2021)

Moreover, there are different types of transformers that can be found in substations. “Transformers at substations can be classified in different (possibly disjoint) groups, with respect to their voltage levels (power levels), function in a power grid, insulation class, or construction, etc.” (Rafique, 2018, Section 3.1.5).

a) “Transmission substation: for connecting two or more than two transmission lines, via grid breakers. These transformers are inserted in the grid system to improve the power efficiency of the system by reducing the transmission line losses.
b) Distribution substation: to decimate the power level for the distribution level consumers, a distribution transformer is used.
c) Collector substation: usually step up transformers, generally are connected to increase the level of power from the generation level, for example, in wind fields for the high power level consumers.
d) Converter substation: these devices can change some important parameters like frequency of the applied signal.” (Rafique, 2018, Section 3.1.5)

3) Transmission Structures (poles, towers)

“Transmission structures support the phase conductors and shield wires of a transmission line. The structures commonly used on transmission lines are either lattice type or pole type. Lattice structures are usually composed of steel angle sections. Poles can be wood, steel, or concrete. Each structure type can also be self-supporting or guyed. Structures may have one of the three basic configurations: horizontal, vertical, or delta, depending on the arrangement of the phase conductors.” (Fang et al., 1999, Introduction and Application, p. 1)

The Grid Structure

According to the German transmission system operator (TSO), 50 Hertz, the electricity grid is divided into four levels. (50 Hertz, 2020b)

1) The Extra High Voltage Grid (220 kV to 380 kV)
2) The High Voltage Grid (110 kV)
3) The Medium Voltage Distribution Grid (3kV to 30 kV)
4) The Low Voltage Distribution Grid (230 V or 400 V)

Moreover, renewable energy projects can be connected to all of the above levels depending on how large their capacity is. For example, large renewable energy projects like off-shore and on-shore wind energy projects as well as large hydroelectric and pumped storage power stations are connected to the Extra High Voltage Grid. The High Voltage grid can accommodate medium renewable energy installations such as on-shore wind energy turbines and large scale photovoltaic installations in addition to medium sized hydroelectric and pumped storage power stations. Smaller renewable energy installations that can be in the form of on-shore wind energy turbines, photovoltaic arrays, rooftop installations, biomass plants, and small scale hydroelectric and pumped storage power stations can be connected to the Medium Voltage Grid. Finally, the Low Voltage Distribution Grid can also be fed electricity produced by small renewable energy installations such as on-shore wind turbines and household rooftop installations as well as small decentralised power stations such as CHP plants. (50 Hertz, 2020b)

2.2.5 Assumptions

The grid connection procedure can vary from project to project and from country to country because each project is evaluated on its own before entering the grid. The projects can also vary in terms of capacity and by referring to the structure of the grid, the prospective renewable energy projects can be connected to all four levels depending on their production capacity. In the case of the estimation for the URR, there isn't one specific project (with defined borders and a specific capacity) to be evaluated. Furthermore, the study of connecting to the grid consists of an extensive analysis of the specific conditions and energy flows and is performed at a regional level generally and more specifically, at a project level meaning that the project's capacity and exact location has to be known. Finally, the renewable energy potentials in the URR found in Report 2.1.1 are mapped according to their usable area. The usable area is spread out continuously over the whole URR region and not in the form of discrete clusters that constitute possible projects at specific locations. In addition, there are no specifications in each of the three countries that determine the minimum or maximum distances that a prospective project should have from the grid in order to be executed. Also, the data available for the structure of the regional grid is a mapping of the different point components of the grid (substations, transmission structures, and transformers) as described in the background information section.

Therefore, because of the conditions stated above, several assumptions were made. Firstly, because the potentials are depicted in the form of a continuous area and not in the form of project clusters (each with specific capacity and defined borders related to each) that can be matched to a certain grid level. Moreover, it is in this case not possible to perform a regional evaluation of the energy flows. Therefore, the study of the proximity of the RES potentials to the grid had to be done statistically. Second, the distances that are chosen in the methodology are based on assumptions that were picked logically but at random in order to evaluate the proximity of the potential to the grid. Third, the grid was assumed to be a sum of its different point components, that are described above.

2.2.6 Methodology

In order to study the proximity to the electricity grid of the potentials calculated in Report 2.1.1, a statistical method was used to calculate the distances that separate the RES potentials from the grid. This method views the grid as a grouping of its different point components (poles, towers, substations) and the RE potential as land area that is spread out within the entire study area. Substations and transformers are considered together because most transformers are found in substations.

By computing the area of the previously found potentials that is located in the vicinity of these different point components, it is possible to draw certain observations about the proximity of the unused renewable energy potentials to the grid.

As a first step, a buffer was created around the different grid components (poles, towers, substations) at different distances (500 m, 1 km, 2 km) to create four proximity zones per grid component where:

1) Zone A: Usable areas situated in this zone are located within 500 m or less from the closest grid connection point
2) Zone B: Usable areas situated in this zone are located within 500 m to 1km from the closest grid connection point
3) Zone C: Usable areas situated in this zone are located within 1 km to 2 km from the closest grid connection point
4) Zone D: Usable areas situated in this zone are located more than 2km away from the closest grid connection point.

In figures 2.2, 2.3, & 2.4, the four proximity zones (A, B, C & D) are depicted around each grid component (poles, towers, & substations respectively) to indicate the significant areas in this study.

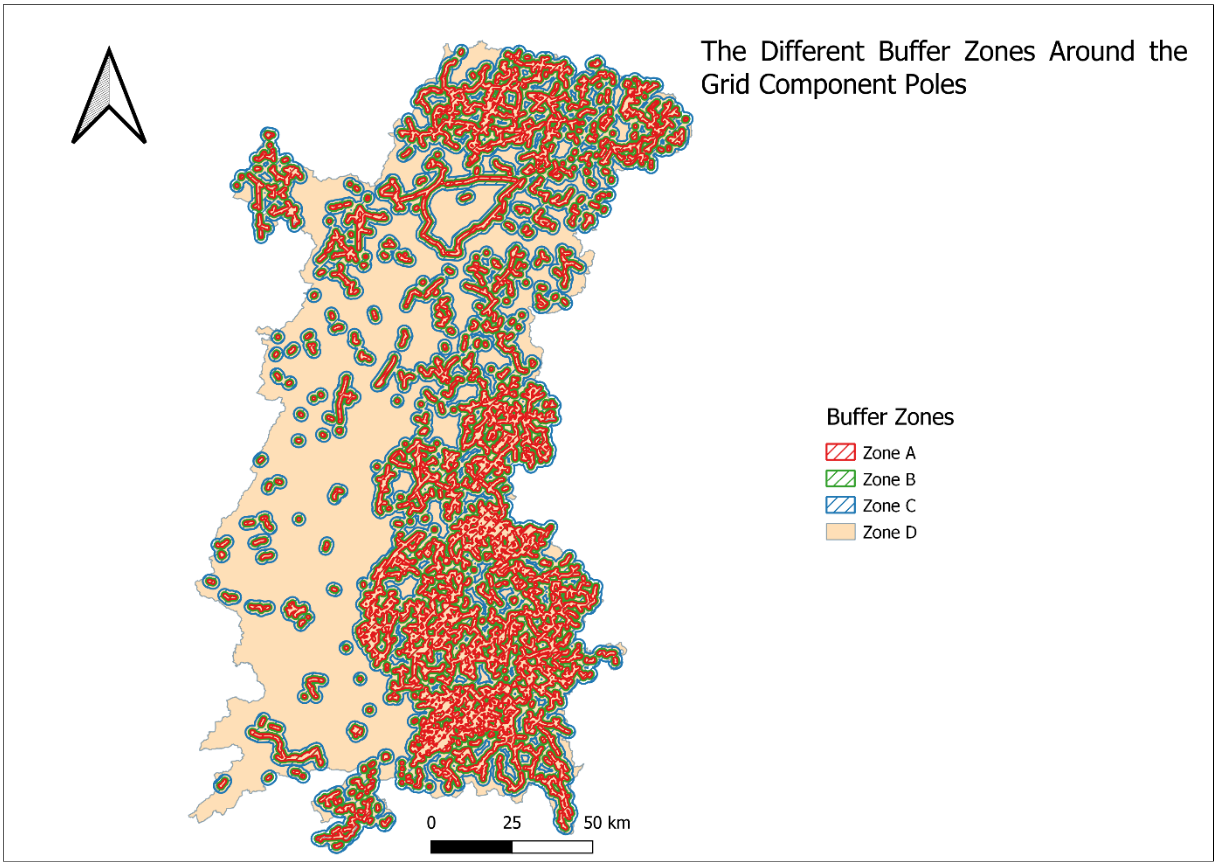


Figure 2.2: Buffer Zones around the Poles

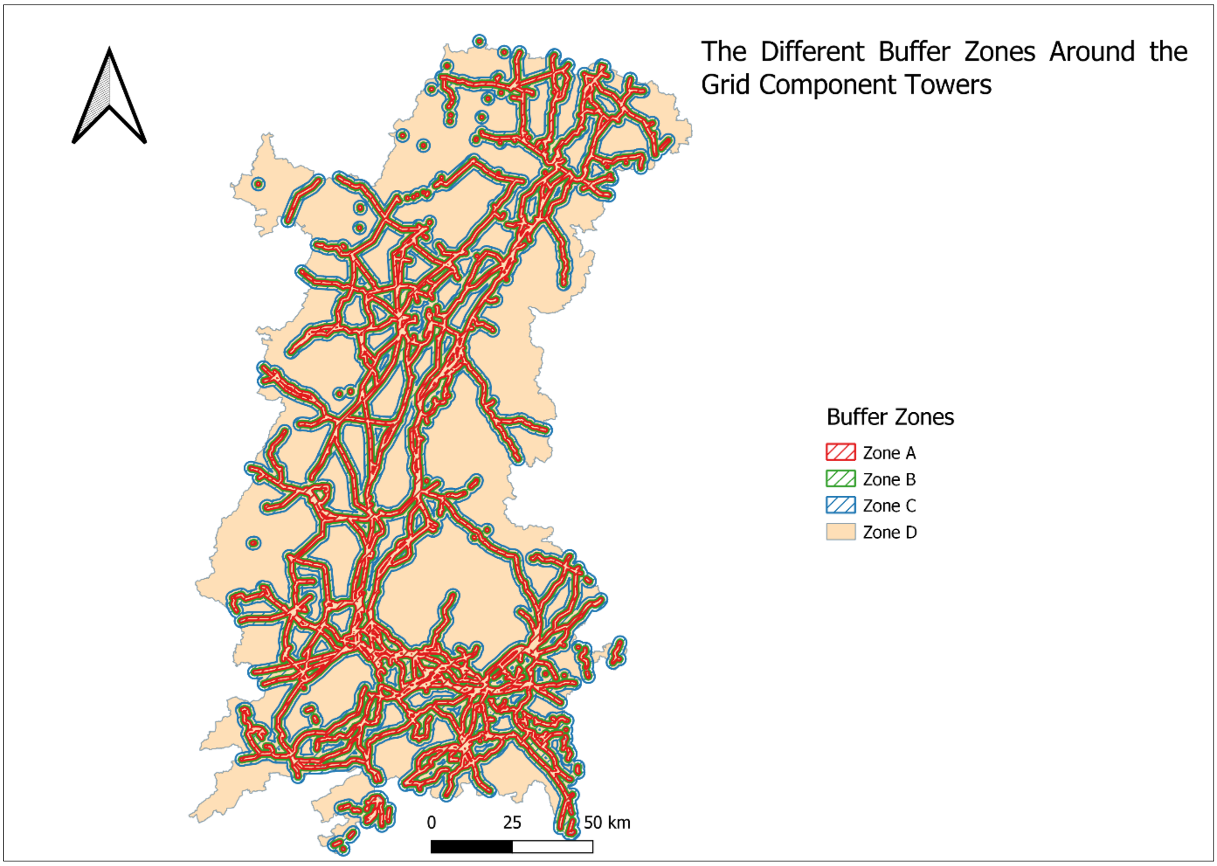


Figure 2.3: Buffer Zones around the Towers

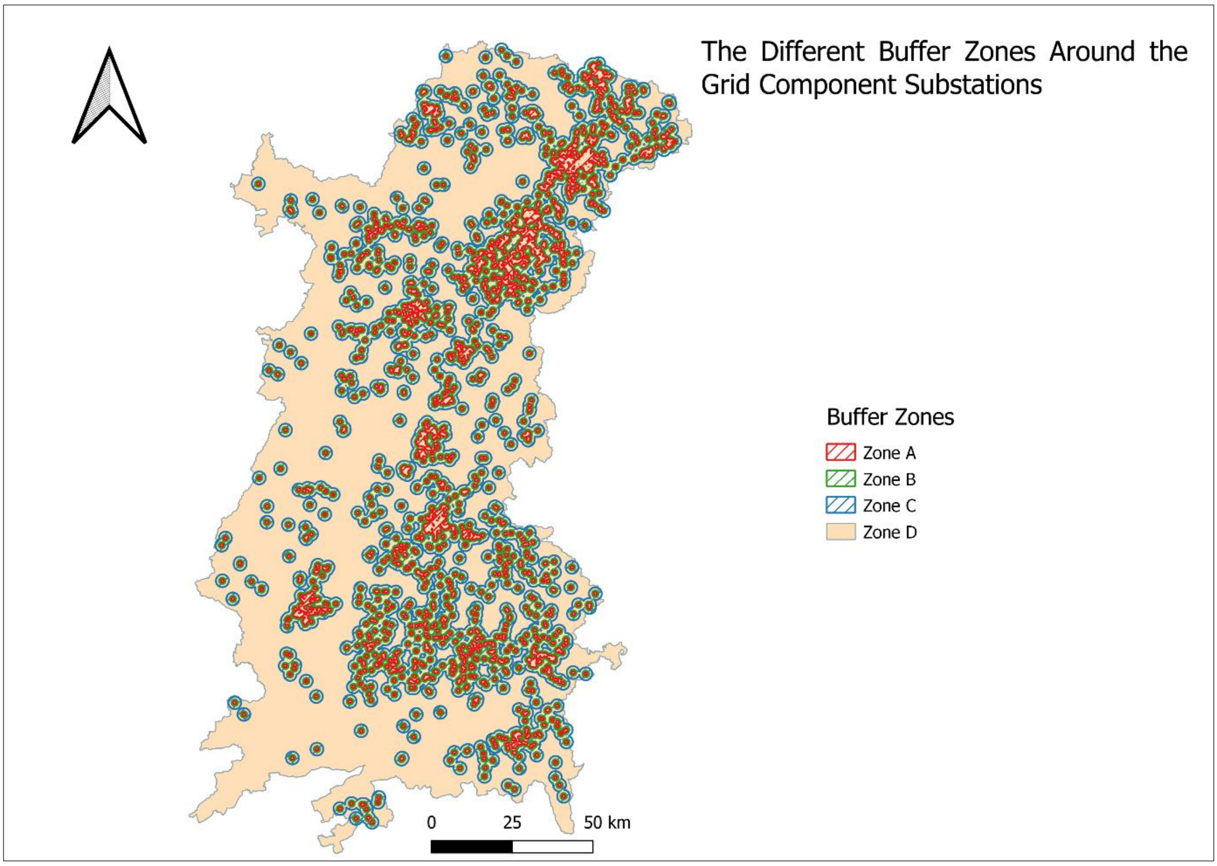


Figure 2.4: Buffer Zones around the Substations

At this point, the zones of the grid components are analysed individually. Taking as an example the towers that are part of the electricity grid, the method is as follows:

a) The area of the four proximity zones (Zones A, B, C, & D) mapped around the towers is intersected with the usable areas of each RES, wind, solar PV (Agro-PV, ground-mounted PV, and Rooftop PV). The resulting intersection area constitutes the usable area situated in each zone. The figures below illustrate the example of the proximity zones around the grid component towers. The same method is repeated for the other two grid components. In figures 2.5, 2.6, 2.7 & 2.8, an example of the results of the grid component towers is portrayed. Figure 2.5 shows RE potential for each source (GM-PV, Agro-PV, Wind, & Rooftop PV) located in Zone A around the towers. Figure 2.6 shows the RE potential around Zone B. Figure 2.7 shows the RE potentials located in Zone C and Figure 2.8 the RE potentials of Zone D around the grid component towers.

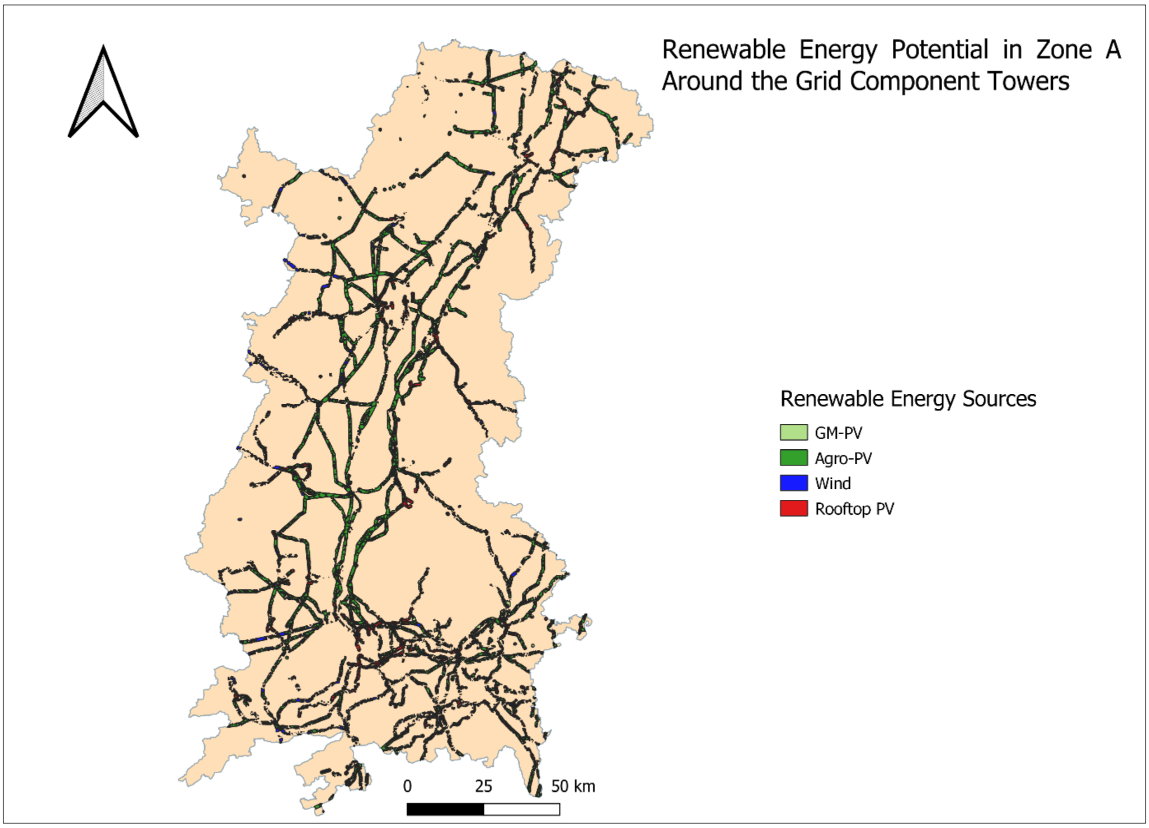


Figure 2.5: RE Potentials in Zone A around the Grid Component Towers

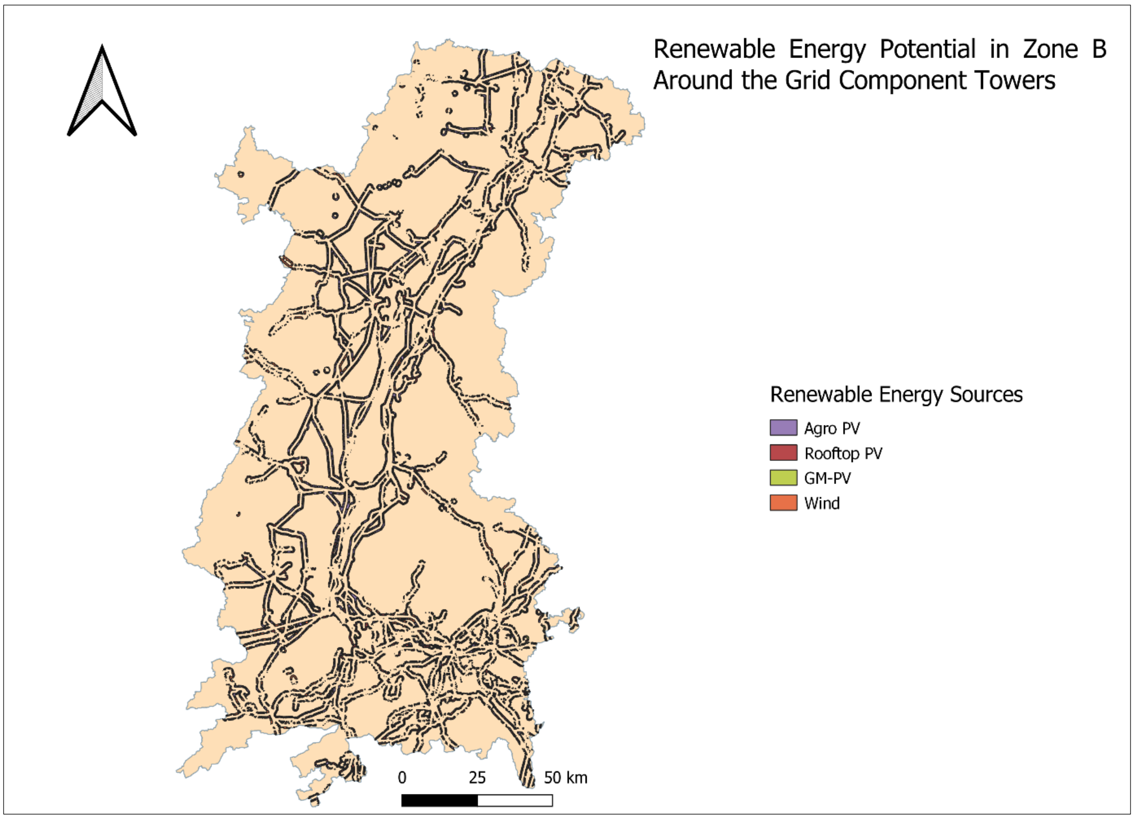


Figure 2.6: RE Potentials in Zone B around the Grid Component Towers

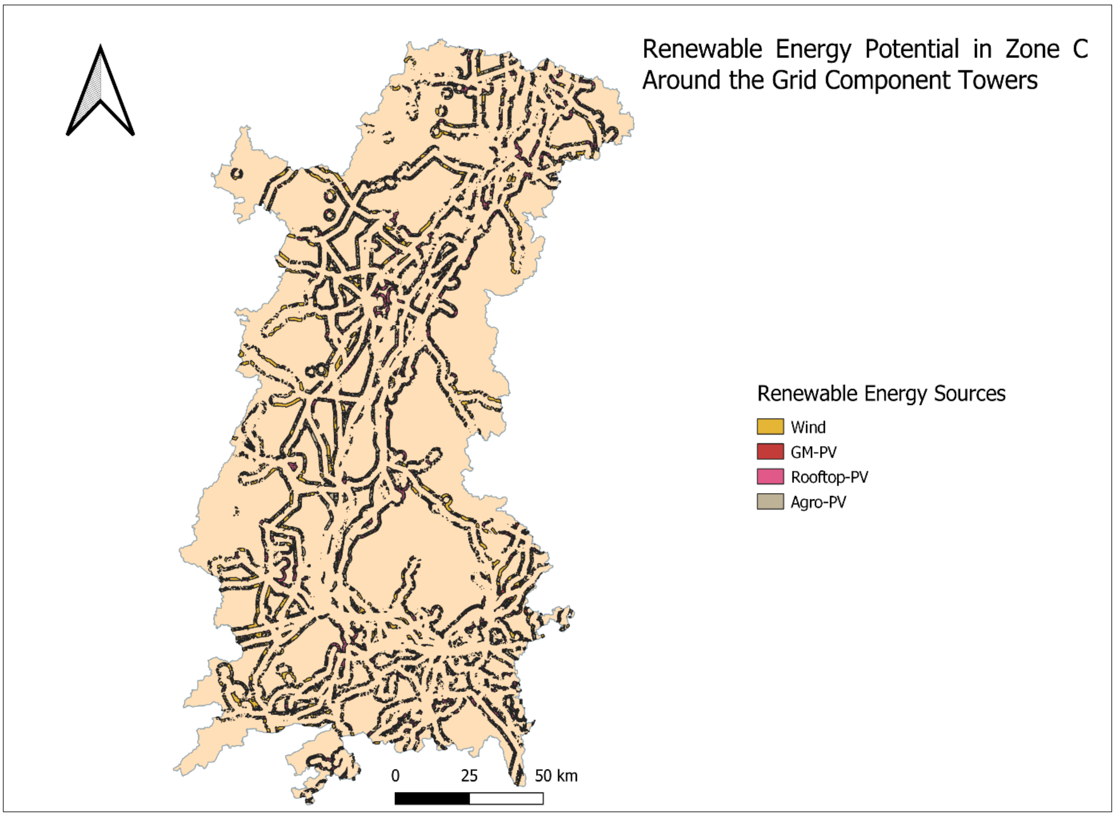


Figure 2.7: RE Potentials in Zone C around the Grid Component Towers

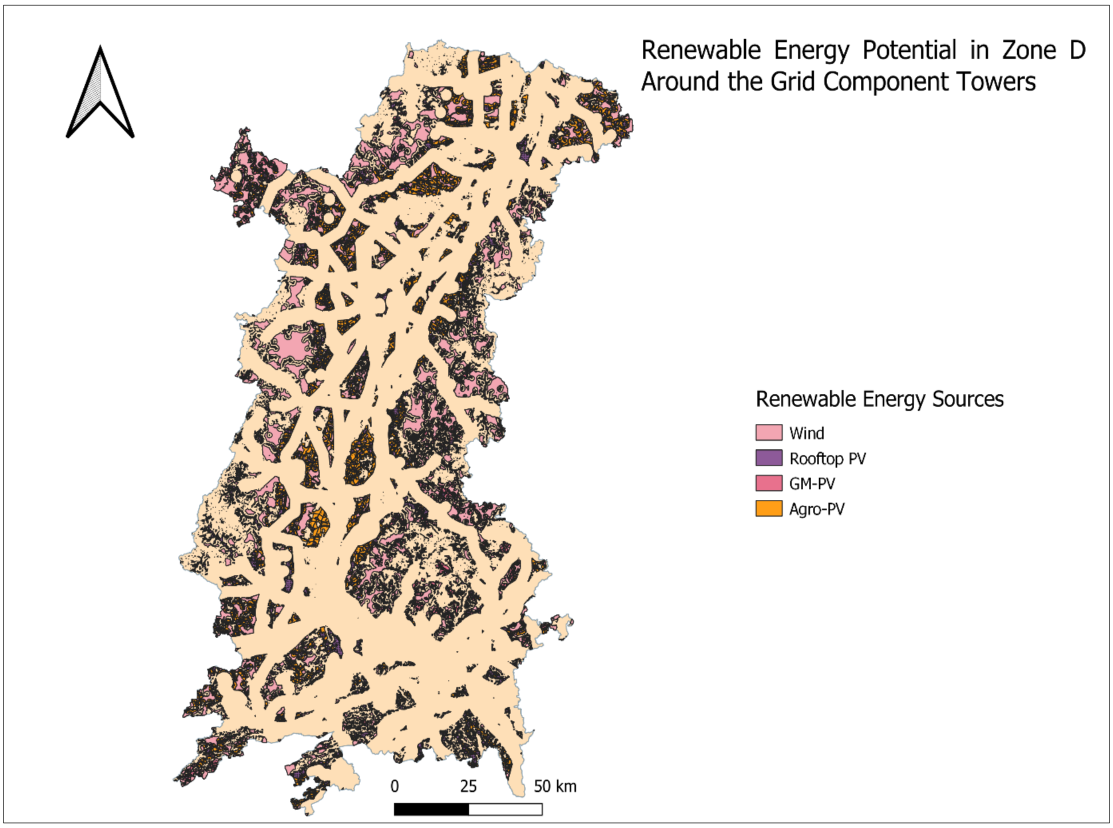


Figure 2.8: RE Potentials in Zone D around the Grid Component Towers

b) For each combination of zone (A, B, C, & D) and RES (wind, solar PV (Agro-PV, GM-PV, and Rooftop PV), the resulting area of the intersection is divided by the total usable area of the RES and the obtained ratio (named the proximity ratio) is given in %. The proximity ratio is calculated with respect to the overall usable area of the renewable energy source. Therefore, it depicts the ratio of area found in the buffer zone with respect to the total area, per renewable energy source and grid component, in %. Larger values of the proximity ratios do not translate into a larger usable area in the proximity zones but rather it means that a larger portion of the total usable area of the RES is found within the proximity zones.

c) After calculations are finished for each grid component, average values for the proximity ratios are calculated and the results are presented in terms of overall grid proximity to the different RES.

2.2.7 Results

Validation Method

By using a more basic methodology to estimate the area needed to supply the energy demand of the URR by the different renewable energy sources (mainly solar and wind), Work Page 3 (WP3) was able to obtain a maximum and minimum estimate of the potential per area of the region (in TWh/km2). Their starting point was the solar irradiation and wind speed and the end result was two scenarios for each renewable energy source, a best case and worst case in the form of an area range (from minimum to maximum) needed to supply 100% of the energy demand of the URR. The maximum area is the area needed to supply the demand when the worst conditions are accounted for (lowest value for solar irradiation or wind speed in the region) and the minimum area is the area needed to supply the demand when the best conditions are accounted for (highest value for solar irradiation or wind speed in the region). While there are differences in the methodology used by both packages, the area range calculated by WP3 provided a good scale of measurement for the accuracy of the results obtained by WP2 and led to more investigations into the RE potentials . Moreover, the range obtained for WP3's study provided a base for comparison and validation of WP2's results especially since there is no previous similar study performed on the region in question to compare with. Therefore, the results included below are the final results, validated and compared to the WP3's scale.

Wind Energy Potential

The total wind energy potential was estimated to be 128 TWh/year. The figure below shows the usable areas for wind (in colour) and the restricted areas (in white). The results are also presented per country and as can be observed, France has the highest technical potential, followed by Germany and Switzerland.

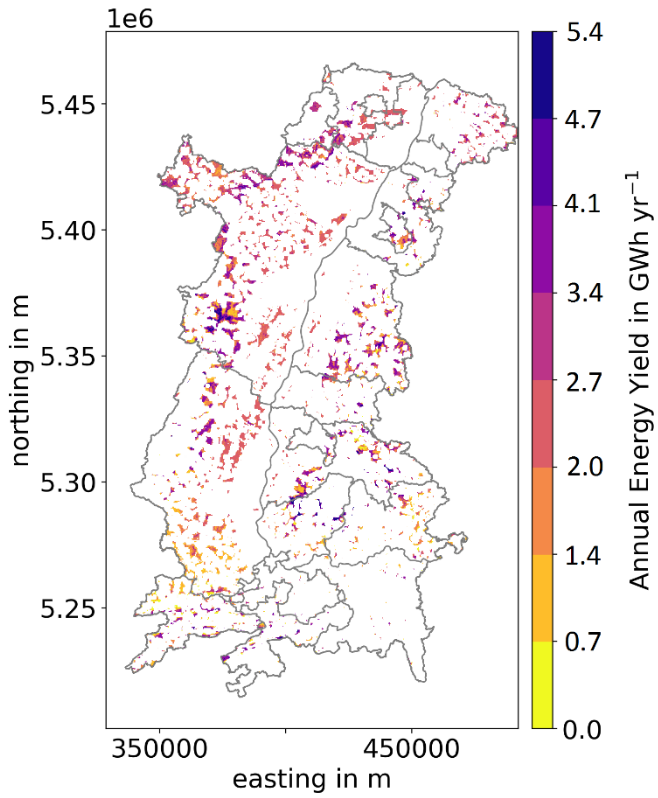


Figure 2.9: The refined wind energy potential distribution in the URR

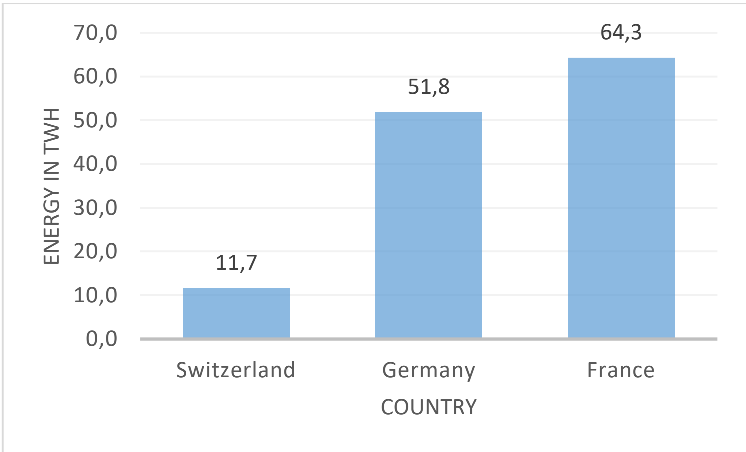


Figure 2.10: The refined wind energy potential distribution per country in the URR in TWh/yr

Solar PV Potential

Solar PV was divided into Agro-PV, GM-PV and rooftop PV. The results presented are also divided accordingly.

Agro-PV

The total potential for Agro-PV was estimated to be 91.5 TWh per year. In this case, the results are presented per municipality meaning that the usable area isn't depicted in the figure below. The results also show that France has the largest share of technical potential in this category followed by Germany and Switzerland as in the case of wind.

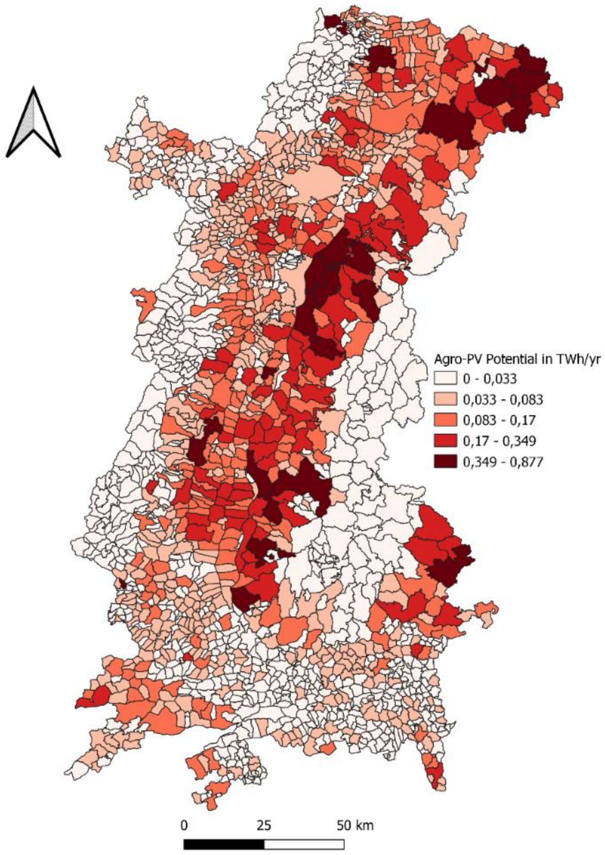


Figure 2.11: The refined Agro-PV Potential in the URR in TWh/ yr per municipality

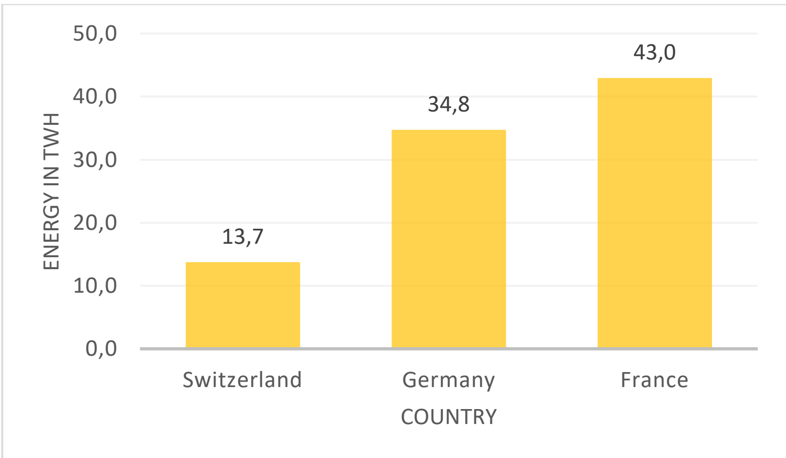


Figure 2.12: The refined Agro-PV potential distribution per country in the URR in TWh/yr

GM-PV

The total potential for GM-PV was estimated to be 68 TWh/year. As in the case of Agro-PV, the GM-PV potentials are presented per municipality. Germany is the country with the highest share of technical potential.

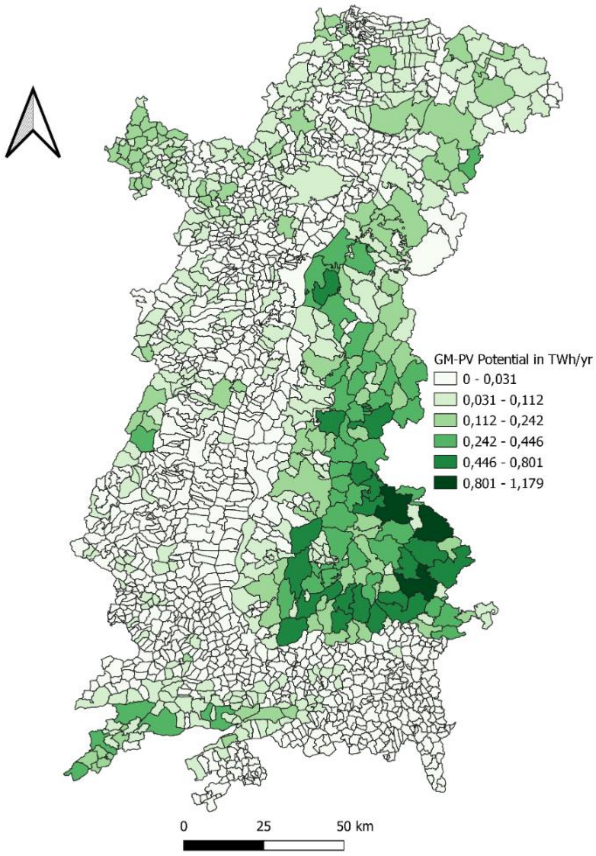


Figure 2.13: The refined GM-PV potential in the URR in TWh/yr per municipality

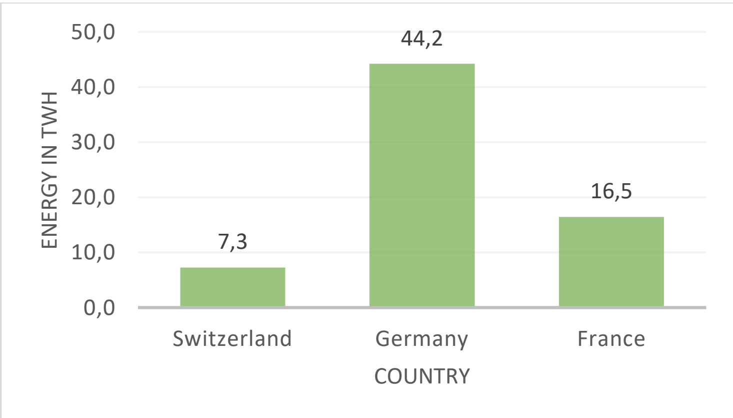


Figure 2.14: The refined GM-PV potential distribution per country in the URR in TWh/yr

Rooftop PV

The rooftop PV results show that Germany has the highest technical potential in comparison to the other countries included in the study. Moreover, the total technical potential was estimated to be 52.2 TWh/year.

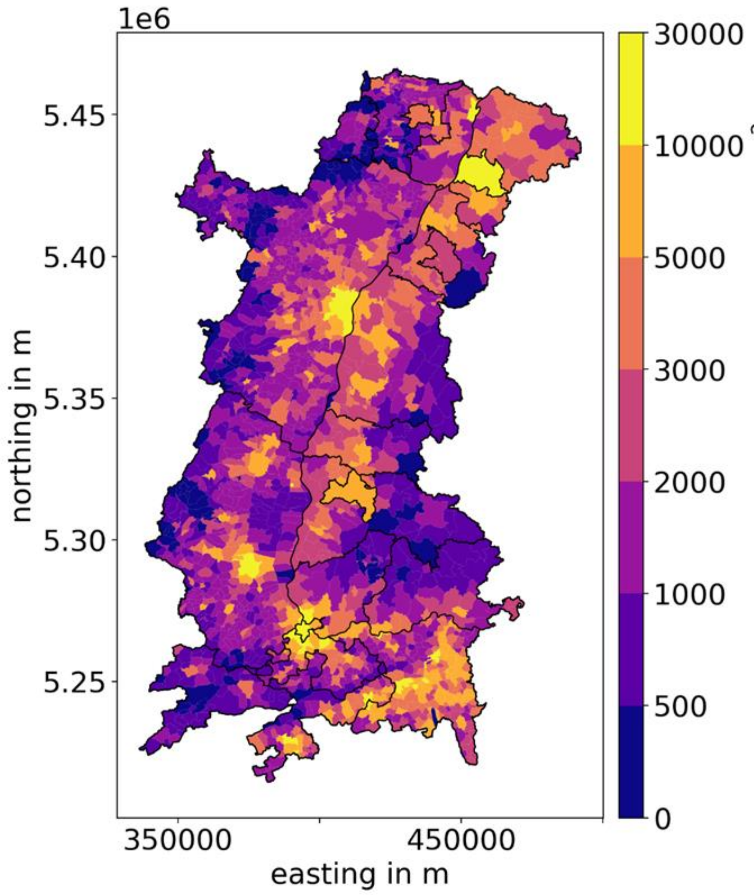


Figure 2.15: Spatial Distribution of the yearly rooftop PV potential in the URR

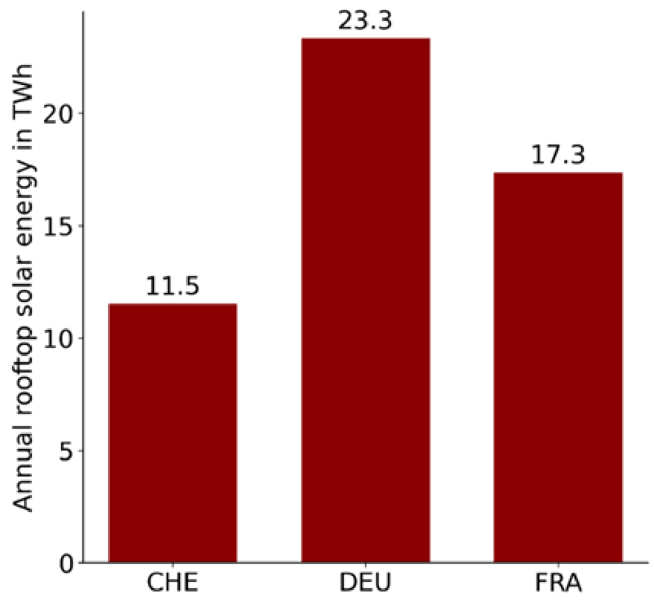


Figure 2.16: Yearly rooftop solar PV Potential in the three countries of the URR

Hydropower

The hydropower potential is the already existing potential as mentioned previously in the methodology of Report 2.1.1. On the French side, according to EDF (n.d.), the 10 French-German turbines produce on average 10 TWh per year. On the German-Swiss side, according to Axpo (2018), there are 11 turbines delivering almost 5 TWh of electricity per year. Assuming that the energy produced can be equally divided over the 11 turbines, 8 turbines would have a combined output of 3.6 TWh. The results are depicted in two categories depending on the countries that border the Rhine.

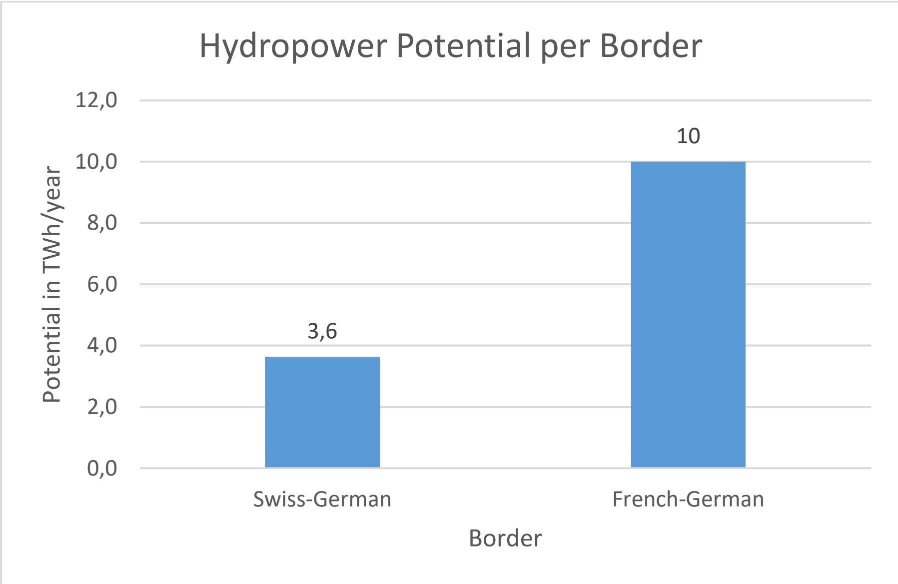


Figure 2.17: Yearly Hydropower Potential per country border in the URR

Biomass & Bioenergy

The actual biomass potential was estimated to be 5.2 TWh. As mentioned in the methodology section, the results are based on data collected for the “Biomass Oui” project and was calculated by multiplying the per capita potentials of each biomass source identified above by the inhabitants of the region; therefore, the results are found on scale larger than the municipal scale because of data availability.

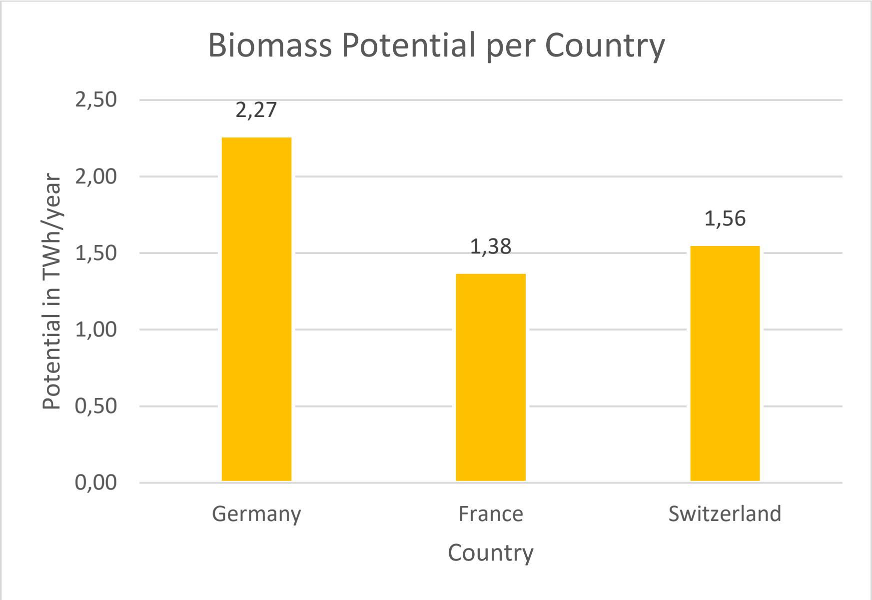


Figure 2.18: Yearly Biomass Potential per country in the URR

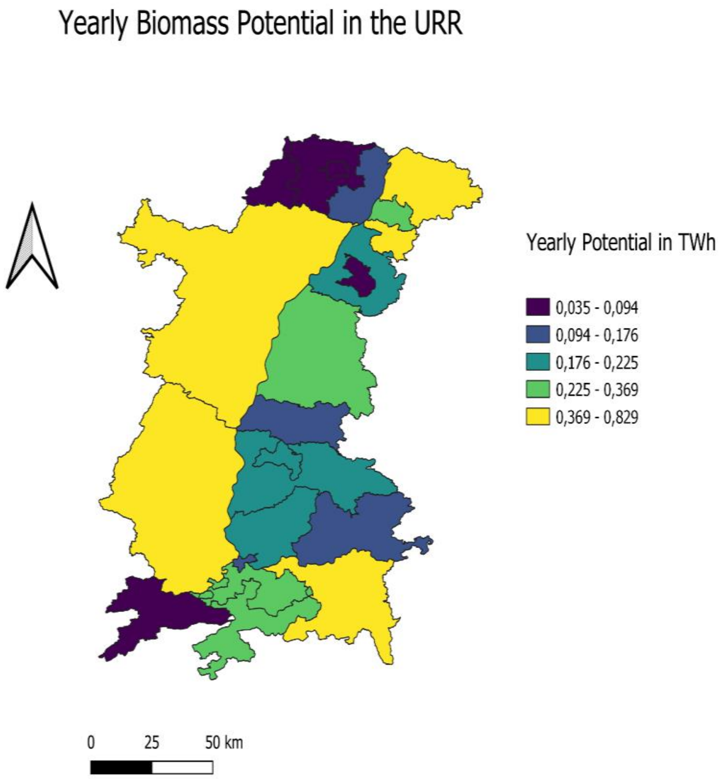


Figure 2.19: Yearly Biomass Potential in the URR

The Total Potentials

According to Fraunhofer ISE (Ed.) (2020), solar PV and wind are considered pillars of the future energy supply. They constitute the bulk of the region's potential and the focus of our study. The final potential results are found in the table below.

The sum of the wind and solar PV technical potentials in the URR is approximately 340 TWh/year. Solar PV is the largest renewable energy source in the region with a total potential of about 212 TWh/year. Solar PV is followed by wind (128 TWh) as the second largest RES. Within the solar PV potentials, the largest potential is for Agro-PV followed by GM-PV and then rooftop PV. However, when it comes to the energy produced per km2, GM-PV has the highest potential and Agro-PV and rooftop PV show comparable energy densities. When the solar PV and wind potentials are added to the other RES (hydro and biomass) whose potential is the actual potential, the RES potential reaches a value of almost 359 TWh/year. Table 2.1 depicts the results divided per source.

Table 2.1: Final RE Potential in the URR including the refinements done for wind and solar

RE Source	Annual Potential (in TWh)
Wind	128
Solar PV Rooftops	52.2
Solar PV Agro	91.5
Solar PV GM	68
Biomass	5.2
Hydropower	13.6

Built-up Potential

The Interreg project TRION-climate, evaluated renewable energy sources in the same study area and came up with a map consisting of all the renewable energy installations in the region (best practice map). The map below is taken from the TRION-climate Report for 2019. (https://trion-climate.net/energieanlagen).

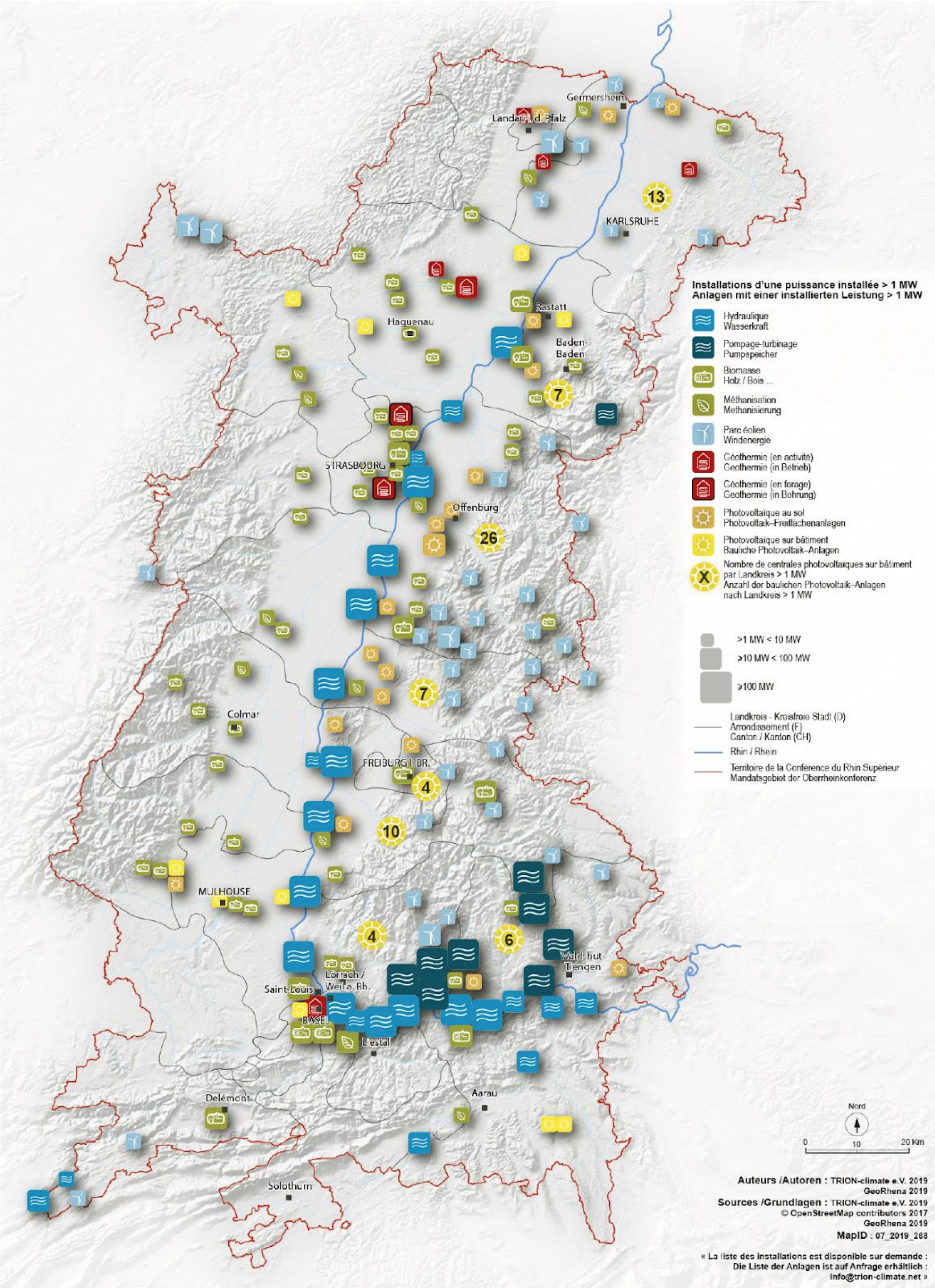
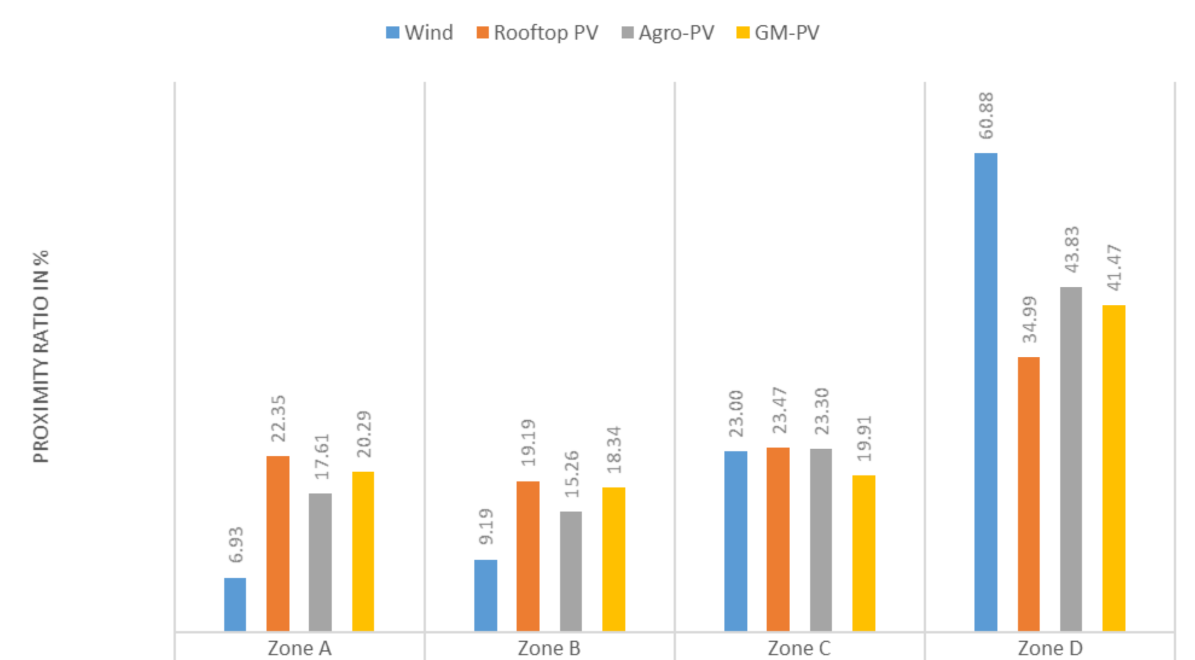


Figure 2.20: The used renewable energy potentials in the URR (TRION-climate e.V., 2019)

The Distance from the Grid Components

The table below depicts the results of Report 2.1.2. Figure 2.21 depicts the results obtained using the methodology described above. In general, it can be observed that the largest areas of potential are located in Zone D. It is observed that the wind potential has the least percentage of area located in Zone A and Zone B while rooftop PV shows the largest percentages in Zone A and Zone B. Rooftop PV is followed by GM-PV that has the second highest percentages in the first two zones. Wind, rooftop PV, and Agro PV exhibit comparable percentages in Zone C (approximately 23%). In general, solar PV potentials have more area located in the first three zones (meaning that their area is mostly located less than 2 km away from the grid) while the area available for wind is mostly (60%) located more than 2 km away from the grid. Of the three types of solar PV, Agro-PV has the highest percentage in Zone D while rooftop PV and GM-PV are generally closer to the grid.

When it comes to the potentials, it can be concluded that solar PV has larger potentials located closer to the grid than wind energy does. Within solar PV, the closest to the grid is rooftop PV followed closely by GM-PV, while Agro-PV is the farthest solar PV type from the grid. The logic behind the results is that rooftop PV is concentrated in cities or buildings that are usually well connected to the grid (or in close proximity to the grid) while GM-PV and Agro-PV are found in arable areas that do not necessarily have to be in close proximity to the grid. The results also seem to indicate that the wind energy potential usable area is the farthest away from the grid.



	Zone A	Zone B	Zone C	Zone D
Wind	6.93	9.19	23.00	60.88
Rooftop PV	22.35	19.19	23.47	34.99
Agro-PV	17.61	15.26	23.30	43.83
GM-PV	20.29	18.34	19.91	41.47

PROXIMITY ZONES

Figure 2.21: Table Comparing the Proximity Ratios of the Different Grid Components

2.3 Scenario Building Based on Case Studies

In Report 2.1.3, the spatial distribution of the potentials at the country level calculated in Report 2.1.1., the distance of the usable area of the potentials from the grid infrastructure found in Report 2.1.2, and the distribution and characteristics of the municipalities are analysed in order to provide insight that enables the building of future research scenarios and case studies. Therefore, it draws on and combines the findings of the first two reports and its important results are summarised below.

First, a quantitative analysis of the potential of RES (solar PV and wind) of municipalities is analysed in the form of two ratios. Ratio A depicts the ratio of the number of municipalities with zero potential to the number of total municipalities and ratio B depicts the ratio of the number of municipalities with above-average potential to the number of total municipalities. The two ratios help give some insight on the logic behind the distribution of the potentials per country.

2.3.1 Calculating Ratios A & B

Solar PV

Table 2.2: Ratio A and ratio B calculated for the Agro-PV potential of the municipalities in the URR

Agro-PV	Number of Municipalities with 0 Potential	Total Number of Municipalities	Ratio A	Average Potential per Municipality (in TWh)	Number of Municipalities with Higher than Average Values	Ratio B
France	128	868	0,15	0,05	346	0,40
Germany	88	377	0,23	0,09	126	0,33
Switzerland	37	464	0,08	0,03	159	0,34

Table 2.3: Ratio A and ratio B calculated for the GM-PV potential of the municipalities in the URR

GM-PV	Number of Municipalities with 0 Potential	Total Number of Municipalities	Ratio A	Average Potential per Municipality (in TWh)	Number of Municipalities with Higher than Average Values	Ratio B
France	442	868	0,51	0,02	240	0,28
Germany	40	377	0,11	0,12	111	0,29
Switzerland	328	464	0,71	0,02	93	0,20

Table 2.4: Ratio A and ratio B calculated for the rooftop PV potential of the municipalities in the URR

Rooftop PV	Number of Municipalities with 0 Potential	Total Number of Municipalities	Ratio A	Average Potential per Municipality (in TWh)	Number of Municipalities with Higher than Average Values	Ratio B
France	1	867	0,001	0,02	204	0,24
Germany	1	377	0,003	0,06	106	0,28
Switzerland	1	462	0,002	0,02	151	0,33

Wind

Table 2.5: Ratio A and ratio B calculated for the wind potential of the municipalities in the URR

Wind	Number of Municipalities with 0 Potential	Total Number of Municipalities	Ratio A	Average Potential per Municipality (in TWh)	Number of Municipalities with Higher than Average Values	Ratio B
France	123	868	0,14	0,08	745	0,86
Germany	81	377	0,21	0,13	321	0,85
Switzerland	168	462	0,36	0,03	294	0,64

2.3.2 The usable area per country

Another important criteria is the usable area per country. The ratio of the usable area per country to the total URR usable area is calculated below for each RES and the results are given in %.

Solar PV

Table 2.6: The per country percentage of usable area to the total usable area for the RES Agro-PV

Country	Agro-PV Usable Area/Total Area in %
Switzerland	47
Germany	15
France	38

Table 2.7: The per country percentage of usable area to the total usable area for the RES GM-PV

Country	GM-PV Usable Area/Total Area in %
Switzerland	11
Germany	65
France	24

Table 2.8: The per country percentage of usable area to the total usable area for the RES rooftop PV

Country	Rooftop PV Usable Area/Total Area in %
Switzerland	22
Germany	45
France	33

Wind

Table 2.9: The per country percentage of usable area to the total usable area for the RES wind

Country	Wind Usable Area/Total Area in %
Switzerland	10
Germany	39
France	51

2.3.3 Analysis of the Potentials and their Distribution

Some important observations for the obtained results presented above are:

Switzerland has the lowest potential out of the three countries in all cases when it comes to all types of solar PV and wind distribution. It also has the lowest number of municipalities in comparison to the other two countries (Tables 2.2, 2.3, 2.4, & 2.5) and land area which could be the reason for the lower potentials calculated. The Swiss part of the URR occupies approximately 3,583 km2 or 17 % of the studied area. Germany and France, on the other hand, respectively occupy more comparable areas of 9,652 km2 (45%) and 8,325 km2 (38%) of the total area, which could explain why Switzerland is lagging behind in terms of RES potential as much of the study is dependent on area. The exception would be the usable area for Agro-PV in Switzerland which is the largest of the three countries as can be seen from Table 2.6.

Moreover, Germany has the largest potential when it comes to rooftop PV and GM-PV (Figures 2.14 & 2.16) . Germany also has the highest percentage of usable area when it comes to rooftop PV and GM-PV (Tables 2.7 & 2.8), which could explain the high potentials calculated. Germany also has the highest number of inhabitants in comparison to the other two countries which could explain the availability of usable areas for rooftop PV and consequently the potential related to rooftop PV. Equally important for the availability of rooftop potential are the two factors: availability of rooftop surface area and solar irradiation.

When it comes to Agro-PV and wind, France has the highest potential in comparison to Germany and Switzerland (Figures 2.10 & 2.12). However, France also has a higher number of municipalities in the study area than Germany and Switzerland (Tables 2.2, 2.3, 2.4, & 2.5). In addition, France has the highest percentage of usable area to total usable area in the case of wind (51%) as can be seen in Table 2.9. As mentioned before, Switzerland has in fact the largest share of the percentage of usable area when it comes to Agro-PV (Table 2.6) which means that France probably receives higher solar irradiation values at the stage of the theoretical potential. Furthermore, when it comes to Agro-PV, Germany has the highest value of ratio A and France has the highest value of ratio B which means that France has the highest percentage of municipalities from the total number to have higher than average values and Germany has a large percentage of municipalities with zero potential of the total (Table 2.2). In turn, France has the highest potential of Agro-PV.

In the case of GM-PV, Switzerland has the highest value of ratio A (highest percentage of municipalities with zero potential) as can be seen in Table 2.3 which could contribute to the fact that Switzerland has the lowest potential for GM-PV. Ratio B on the other hand is comparable for Germany and France which have higher potentials of GM-PV. Interestingly, for rooftop-PV, all of the countries have a small ratio A meaning that there is a very small number of municipalities with no potential as can be observed in Table 2.4. Meanwhile, Switzerland has the highest number of municipalities with above-average values in this category. Finally, for wind energy, Switzerland has the highest value of ratio A and France and Germany have comparable values of municipalities with above average potential values (Table 2.5).

On the other hand, by taking into consideration the study of the distances of the usable area of the RES from the grid from Figure 2.21, it can be observed that GM-PV and rooftop PV also have the highest percentage of usable area that is located close to the electric grid components or located in zone A & zone B as explained in Report 2.1.2. The highest potential for both and the largest usable area is found in Germany, so it is also possible that Germany is better connected than the other two countries or that the study is limited as specified in Report 2.1.2 by the availability of public country grid data.

2.4 Analysis of Geological Storage of Renewable Energy

Hydrogen storage in geological units of the “Oberrheingraben” (ORG) is possible in principle and the storage of energy up to 11 TWh would be feasible. While storage in pore reservoirs is very much dependent on local geological conditions and requires area-wide detailed (preliminary) investigations, the area in which salt cavern storage is possible can be well spatially delimited. Therefore, the following sequence is recommended for future geological energy storage in the ORG:

1. Salt caverns in the salt diapirs of the southern ORG (Bad Krozingen-Colmar-Wittenheim)
2. Salt caverns in the salt diapirs in the southern ORG (Wittelsheim-Staffelfelden)
3. Pore storage facilities in Tertiary sandstones (marginal areas of the ORG, also in the northern OR (see existing gas storages)
4. Pore storages in the permo triassic sandstones of the ORG

For a detailed potential analysis of the salt diapirs and salt layers in the southern ORG a high resolution 3D model is needed which should be based on (new) high resolution seismic data as well as existing borehole data. Such a project should be approached together with partners from the industry (energy companies/grid operators, salt cavern manufacturers (e.g. DEEP.KBB) as well as the corresponding geological state offices.

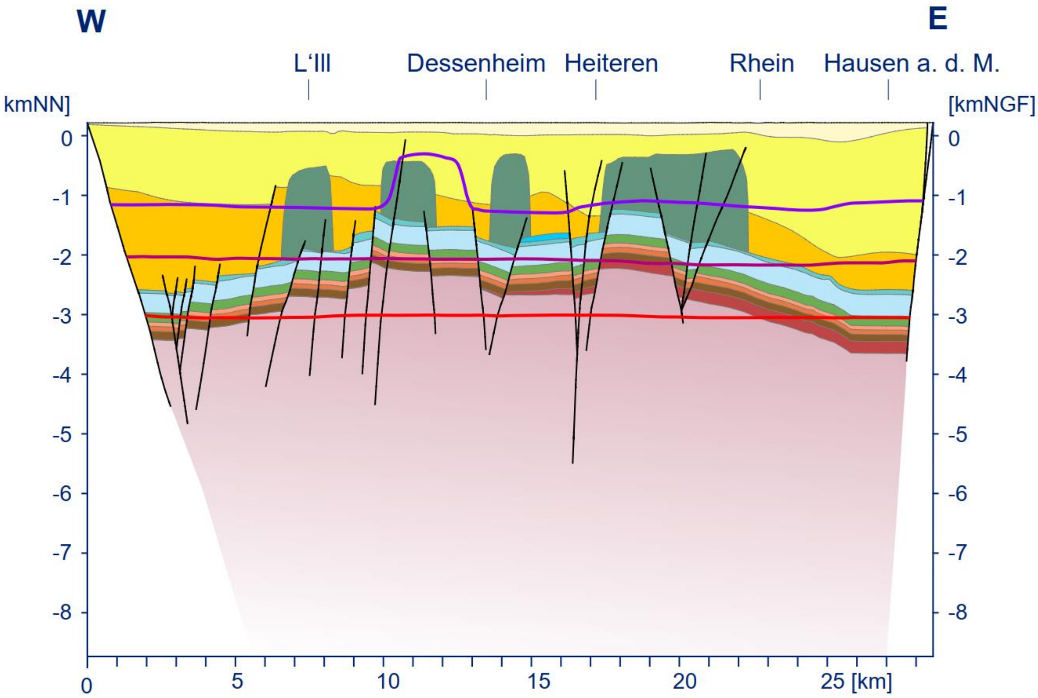

W
E
L'Ill
Dessenheim
Heiteren
Rhein
Hausen a. d. M.
kmNN]
[kmNGF]
0
-1
-2
-3
-4
-5
-6
-7
-8
0
5
10
15
20
25 [km]

Figure 2.22: West-east profile through the ORG slightly north of Bad Krozingen (see Fig. 8). The salt diapirs are clearly visible and reach a thickness of more than 1.5 km. From GeORG-project team (2013)

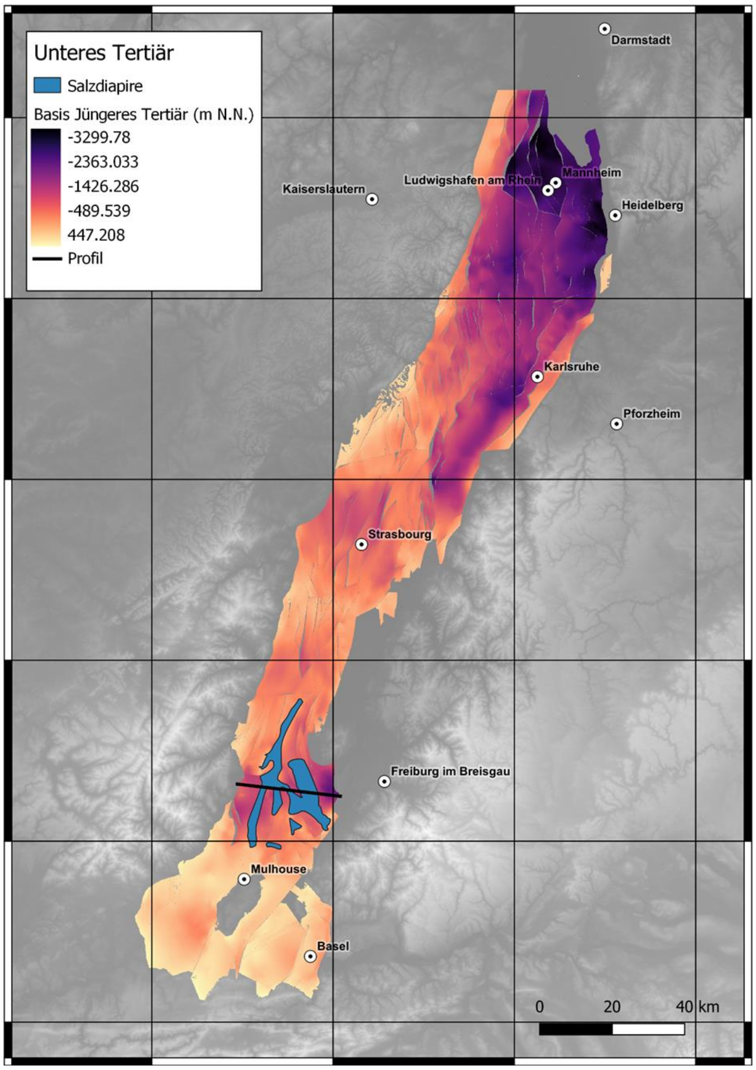


Figure 2.23: Location of the salt diapirs in the ORG. The profile line marks the location of the profile in Figure 2.22. Based on the GeORG-Project team (2013)

Chapter 3. Work Package 3: Modellierung und Szenarienbildung für das Stromsystem

The energy production necessary for the functioning of our modern societies is largely through the burning of fossil fuels. This combustion leads to greenhouse gas emissions into the atmosphere. It is now scientifically proven that these emissions cause global climate change. There is an urgent need to replace fossil fuels with less polluting energy sources. Using renewable resources such as wind, sun and water to generate electricity is an effective way to reduce greenhouse gas emissions. In Europe, it is crucial that each region plays its part by making the best use of the renewable resources at its disposal. The aim of WP3 of the RES-TMO project is to develop the most efficient electricity generation strategies to reduce the greenhouse gas emissions of the Upper Rhine region. Based on the main characteristics of the electricity system of the Upper Rhine region, such as electricity demand and the potential for electricity generation from renewable energy sources, we develop scenarios to better understand future developments and to provide policy makers with tools for their policy decisions. Two mathematical models are used for this purpose: PERSEUS-EU and REPM.

PERSEUS-EU is a model of the European electricity system in which the electricity systems of the individual countries are represented as interconnected nodes. Within the framework of RES-TMO, the Upper Rhine region was integrated into the model as an independent region. We examine scenarios up to the year 2050 in which the EU climate targets are achieved in the electricity sector. In addition to renewable energies, we also include electricity storage technologies in our analyses. The calculations show that solar power generation in particular will find favourable conditions. For the use of wind energy, which also plays an important role in the model calculations, locations outside the study area of the Upper Rhine region offer even better conditions, which is why the expansion of wind energy is mainly taking place there. However, in order to actually be able to use the electricity generated there, we are dependent on an expansion of the electricity grid. Therefore, in a second step of the project, we are also analysing the range of possible scenarios with a more balanced mix of electricity generation from wind and solar energy in the Upper Rhine region and their influence on the regional need for electricity storage and controllable generation capacities. For this purpose, the REPM model is used.

The REPM model focuses on the Upper Rhine region. The model is designed to generate all possible scenarios of electricity generation. To do this, it varies the share of volatile resources (solar and wind power) in the electricity mix and uses this to calculate the amount of energy that needs to be stored or supplemented by controllable resources so that electricity demand is secured at all times. All possible scenarios generated by the model are then classified into different categories to select representative scenarios. Finally, different types of energy generation and storage technologies are mapped in the model to calculate key characteristics such as costs, greenhouse gas emissions or land requirements of the selected scenarios. In this way, decision-makers receive information on a reduced number of scenarios to support the decision-making process.

3.1 Scenarios for the TMO electricity system until 2050

In order to enable comprehensive scenario analyses, the energy system model PERSEUS-EU was extended in this project to include the Upper Rhine region as part of the European electricity system. This section briefly addresses the main assumptions and presents the main results of the modelling work. After a critical appraisal, the main conclusions follow.

3.1.1 Modelling and assumptions

The TMO is strongly interconnected with the surrounding countries. In order to understand the complex interactions between countries and market areas, the PERSEUS-EU energy system model was used. Scenarios were developed for the composition of power generation capacities in the TMO until 2050. The model represents the European energy system model as a linear optimisation problem, minimising the total system expenditure (Heinrichs 2014; Rosen 2007; Keles und Yilmaz 2020). The objective is to determine electricity generation capacities that meet key policy frameworks such as the avoidance of greenhouse gas emissions. The political framework conditions examined also include assumptions on CO2 prices, nuclear policy in the various countries of the Upper Rhine region and measures to phase out coal. For a detailed description of the assumptions on the political framework conditions, see Report 3.1.3. Furthermore, the development of electricity demand in the Upper Rhine region (Report 3.1.1) and the expansion of transmission capacities (Report 3.1.2) have to be considered.

The transmission capacities available for the commercial exchange of electricity between the TMO to the surrounding countries depend on various technical circumstances, which could only be partially considered in this project. Therefore, the capacities were varied between 0% and 70% of the thermal capacity in order to achieve robust results in this way with regard to the resulting power plant park.

3.1.2 Results

By 2050, major decisions will have to be made about the composition of electricity production in Europe. For each region, the question is which technologies should best be used to completely avoid greenhouse gas emissions by 2050. Against this background, this section presents the main results of work package 3. First, we discuss the results on the capacity development of renewable energies and storage technologies. Furthermore, we discuss the question to what extent an independent market area in the TMO can contribute to making the European energy system more efficient. We discuss the self-consumption rate and address model sensitivities regarding critical assumptions.

3.1.2.1 Development of renewables and storage

This section discusses the results of the model calculations with regard to the resulting installed capacities of renewable energies and storage technologies. As mentioned at the beginning, it is assumed in each scenario that greenhouse gas emissions in the electricity sector are to be avoided by 2050. The achievement of this goal is supported by an assumed increasing CO2 certificate price (IEA, 2016).

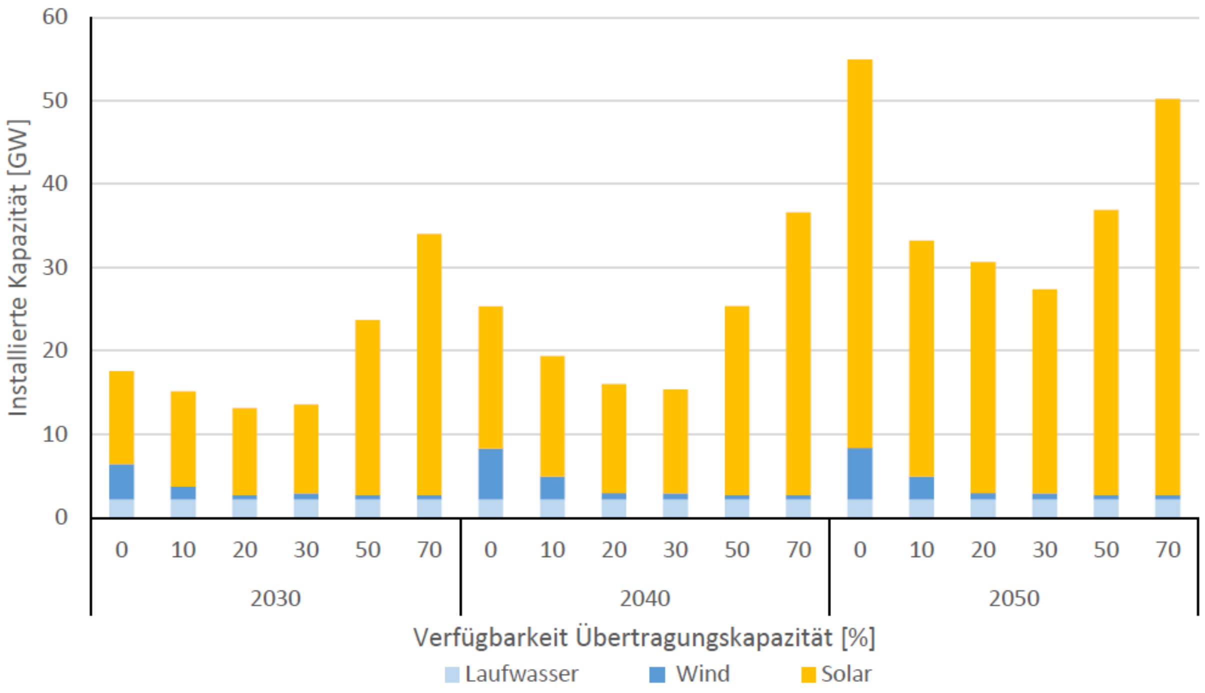


figure 3.1: Installed capacities of renewable energies in the Upper Rhine region under varying availability of transmission capacities to neighbouring countries (own calculations)

figure 3.1 shows the installed capacities of renewable energies in the Upper Rhine region. In order to take into account the influence of the transmission grid boundaries at the nodes, their availability was varied. The course of the run-of-river capacities shows our assumption that no additional large-scale power plants are possible on the Rhine. Biomass was neglected in this representation due to its low degree of expansion. In the case of wind energy, this representation shows an interesting phenomenon: From a system point of view, the installation of additional wind turbines in the Upper Rhine region is only economical under the assumption of weak connections to neighbouring countries, since a significant addition only occurs in the model runs with 0 or 10% availability. This suggests that, from a system perspective, locations outside the Upper Rhine region offer higher wind yields, so that use within the Upper Rhine region only becomes economic in cases of increased independence from neighbouring countries. In the extreme case of complete independence, this results in an installed capacity of 6 GW of wind energy. In the scenarios that rather reflect the current grid situation, on the other hand, there is only a small expansion of wind energy. In the 50% case, for example, there is only an installed capacity of 477 MW in the region.

The course of the installed capacity of solar plants is also interesting. With variation of the transmission capacity to the neighbouring countries, a "U"-shaped course emerges, in which considerably more solar capacity is added in the marginal cases than in the middle cases. In the case of full self-sufficiency, this can be explained by the need to cover the load in the Upper Rhine region and the requirement that this has to be done emission-free by 2050. In case of availability of 70% of the transmission capacities, solar electricity is increasingly produced in the German part of the Upper Rhine region and exported to Germany, as the solar potentials in the Upper Rhine are larger than the national average. At the same time, the French part purchases cheap electricity from France and refrains from installing its own solar plants with increasing availability of transmission capacities.

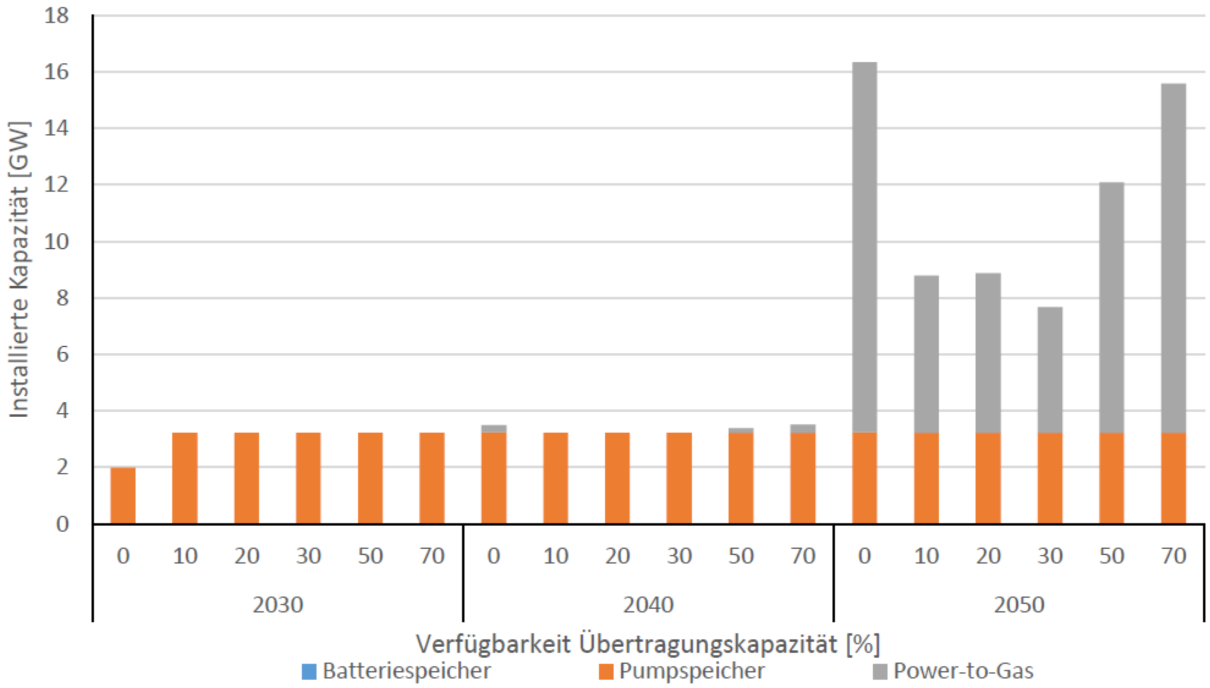


Figure 3.2: Installed capacity of storage facilities in the Upper Rhine region under varying availability of transmission capacities to neighbouring countries (own calculations)

In addition to the renewable energy capacities, figure 3.2 shows the development of the installed capacity of storage facilities in the Upper Rhine region. For the capacity of pumped storage, a consistent picture emerges: the capacity in the region will in (almost) all cases already be increased to its assumed maximum potential in 2030. Battery storage will hardly be installed in the region under the assumed framework conditions. Only in the case of full autonomy, there is an expansion of about 17 MW in 2040. For the Upper Rhine region, this low expansion of short-term storage can most likely be explained by the high availability of pumped storage as a specific feature of the Upper Rhine region. The development of capacities for the generation of synthetic gas (power-to-gas, PtG) are largely proportional to the development of installed solar capacity. Accordingly, an increase in installed solar capacity in 2050 by 1 GW entails an increase in installed PtG capacity of about 0.23 MW. The almost constant ratio of both parameters suggests that PtG is essentially used to store solar power generation at peak times in order to cover demand at other times. Furthermore, it is striking that only in the marginal cases considered does a small addition of PtG take place before 2050.

3.1.2.2 The TMO as an independent market area

In order to assess the effectiveness of the introduction of a market area encompassing the Upper Rhine region, two steps have to be taken. First, existing studies are examined to see whether the introduction of a separate market area can be derived from them. Important here are above all existing bottlenecks at the borders of the new area and the question of whether the introduction of such a market area is envisaged in the bidding zone reviews.

In a second step, the PERSEUS-EU model, which was further developed in the project, is used in which the Upper Rhine region is mapped in the form of three sub-areas. The price differences between the neighbouring countries and the sub-regions of the Upper Rhine region serve as an essential indicator of whether the zoning can contribute added value to congestion management and, moreover, whether additional investment incentives emanate from its introduction. Similar to the approach in the literature based on nodal prices, it can thus be assessed whether the introduction of a bidding zone for the Upper Rhine region leads to significant price differences that make such a division desirable.

Bottlenecks of a TMO market area

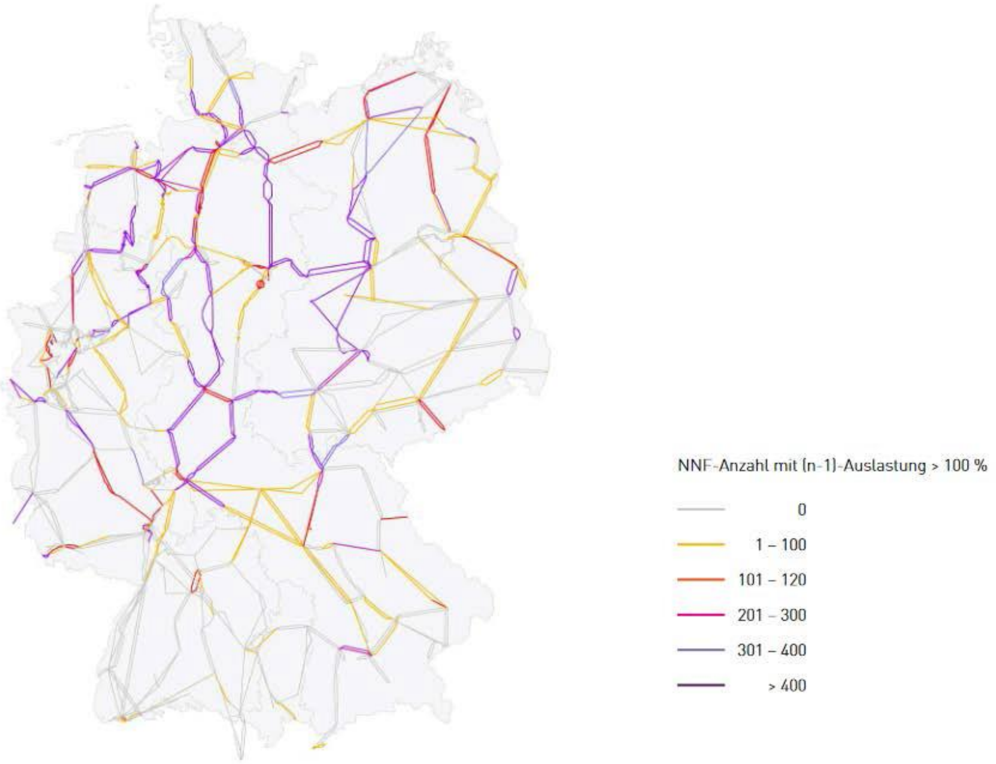


Figure 3.3: Frequency of utilisation above 100% in case of failure of a network element in the "starting network" (NEP 2021, p. 136)

In order to ensure security of supply in the long term, the European transmission system operators regularly develop scenarios to plan the expansion of the electricity grids, taking future developments into account (NEP 2021; RTE 2019). Among other things, grid bottlenecks of the existing grid and the grid under construction are analysed and can thus provide indications as to whether bottlenecks are to be expected at the borders of the Upper Rhine region. For Germany, Figure 3.3 shows the frequency of utilisations above 100% in the "starting grid" of the German Network Development Plan 2021 (NEP 2021). It is noticeable that no significant overloads are expected in the German sub-area of the Upper Rhine region in south-west Germany. The French network development plan (Schéma Décennal de Développement du Réseau; SDDR) also sees no significant congestion in the region until 2035 (RTE, 2019, p. 75). Furthermore, the bidding zone review of the European transmission system operators examined different zone divisions based on expert assessments (ENTSO-E, 2018). The divisions made here do not provide for a bidding zone that would come close to the geographical spread of the Upper Rhine region.

In summary, it can be said that a market zone encompassing the Upper Rhine region in the European electricity market is not envisaged in the long-term plans to date. The evaluation of the congestion anticipated in the network development plans also does not indicate that the introduction of such a market zone would lead to significant improvements in the efficiency of the European electricity market. In order to gain a better intuition for the effects of the introduction of the Upper Rhine bidding zone, we examine below the resulting electricity price differences between the parts of the Upper Rhine region and the respective neighbouring countries.

Model-driven analysis

To further investigate whether a bidding zone in the Upper Rhine region would lead to price differences between the countries and the sub-regions, we use the energy system model PERSEUS-EU. In this way, we can estimate whether the transmission lines at the borders of the Upper Rhine region could represent market-relevant bottlenecks. Since only the thermal capacities of the respective transmission lines are known within the framework of this project and further network calculations are beyond the scope of the project, we approach this question via a sensitivity analysis.

From 2025 at the latest, the electricity market regulation of the European internal market stipulates that, after deduction of any necessary safety margins, 70% of the transmission lines must be available for market operation. The safety margin may vary depending on the transmission line. This means that there is uncertainty about the capacity to be made available to the market at the interconnectors between the Upper Rhine region and the surrounding countries. Due to this uncertainty, we consider three model variations in the following (Figure 3.4, 3.5 & 3.6). We vary the capacity available to the market-driven electricity exchange so that 70%, 50% or 30% of thermal capacity is available in the variations. The 70% case represents the optimistic scenario that no security margin is to be kept available, the 30% case accordingly that a significant margin is to be kept available to ensure secure system operation.

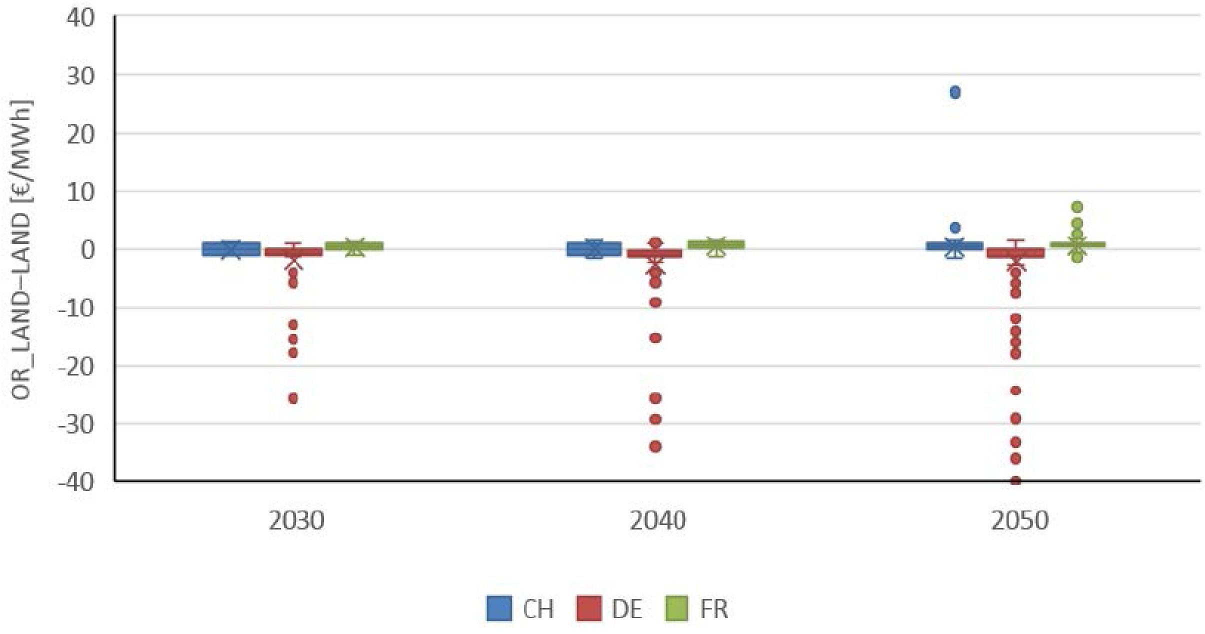


Figure 3.4: Price differences (OR_LAND - LAND) between the sub-regions of the Upper Rhine region and the neighbouring countries assuming the availability of 70% of the thermal capacities of the transmission lines. For visualisation reasons, some negative outliers were not shown

Figure 3.4 (70%) and Figure 3.5 (50%) accordingly show that in both cases no significant price differences are to be expected between the areas of the Upper Rhine region and the neighbouring countries. Only in a few rare hours do significant price deviations occur. Especially the electricity in the German part of the Upper Rhine region tends to be cheaper than the electricity in the rest of Germany. This can be explained by the strong expansion of solar energy in the Upper Rhine region, which finds better conditions here than in large parts of Germany.

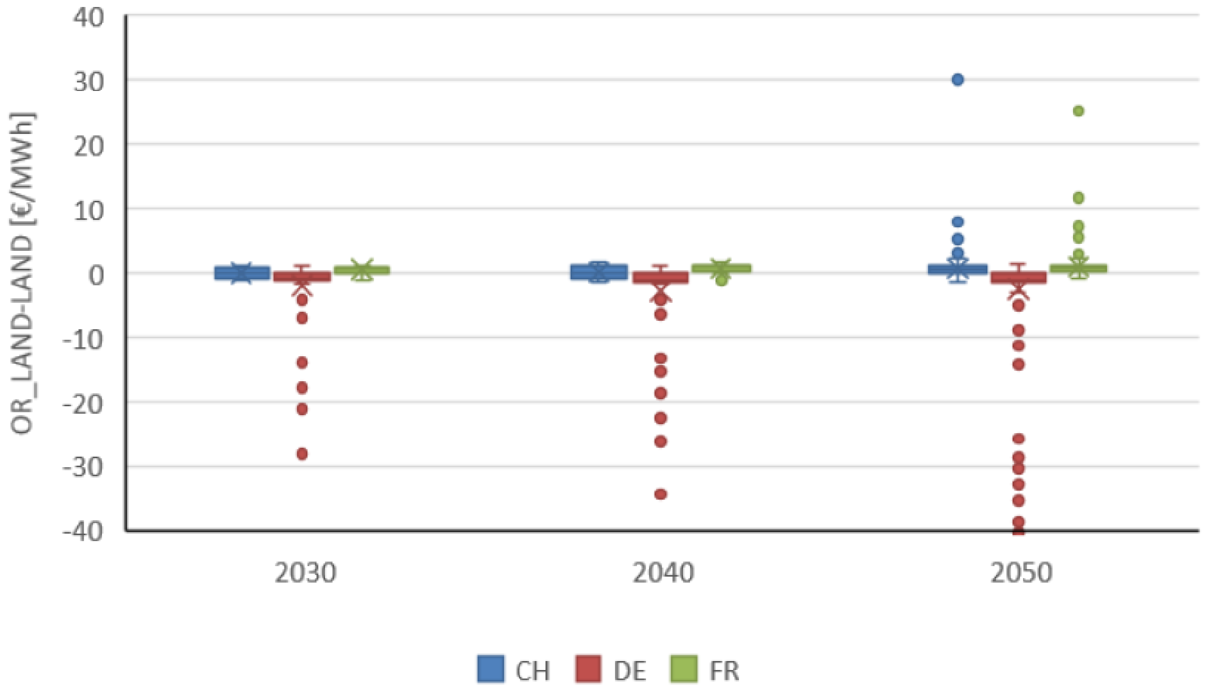


Figure 3.5: Price differences (OR_LAND - LAND) between the sub-regions of the Upper Rhine region and the neighbouring countries assuming the availability of 50% of the thermal capacities of the transmission lines. For visualisation reasons, some negative outliers were not shown

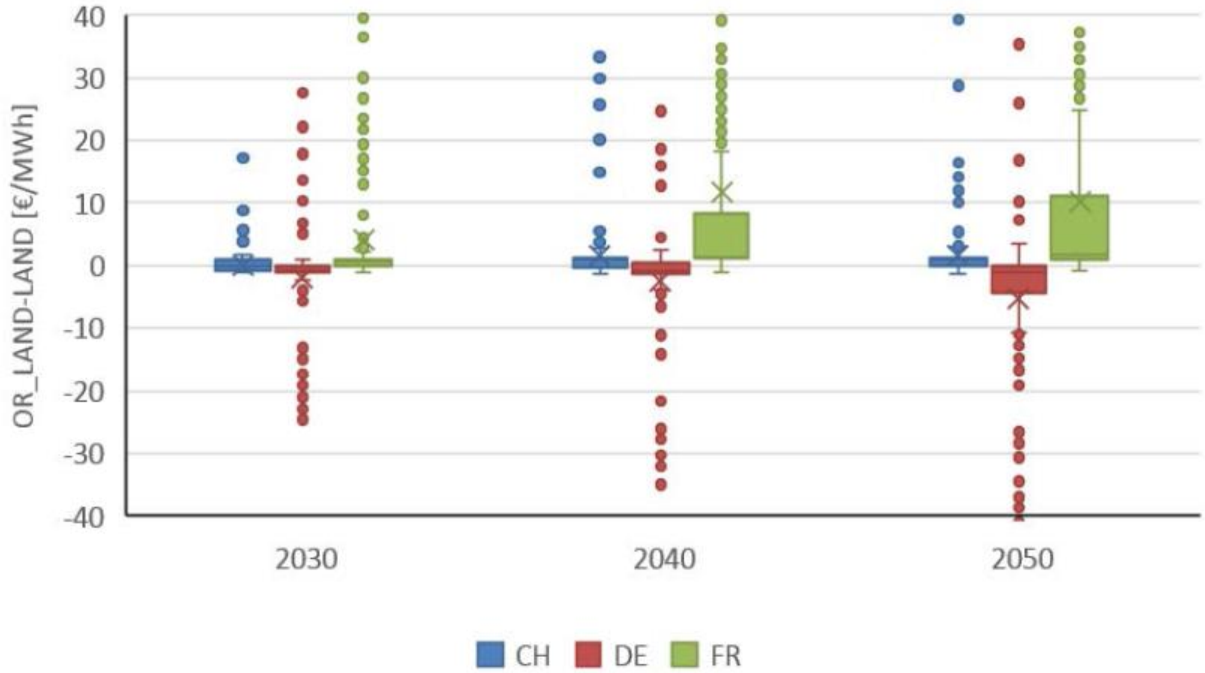


Figure 3.6: Price differences (OR_LAND - LAND) between the sub-regions of the Upper Rhine region and the neighbouring countries assuming the availability of 30% of the thermal capacities of the transmission lines. For visualisation reasons, some negative and positive outliers were not shown

Only in the pessimistic case that 30% of the thermal transmission capacity is available for commercial electricity exchange, relevant price differences arise in the years 2040 and 2050. Especially between France and the French part of the Upper Rhine region, a regular positive price difference develops: Here, the electricity price in the Upper Rhine region is higher than in the core area of France. The electricity supply from nuclear power plants ensures low marginal costs of the electricity produced here compared to the Upper Rhine region, where nuclear power plants are no longer installed. Nevertheless, the observed price differences are almost 75% below 10 €/MWh.

3.1.2.3 Self-consumption in the TMO

Figure 3.7 shows the degree of self-sufficiency of the Upper Rhine region in the different model runs. In 2030, more electricity will be generated in the region than demanded in all cases. The picture changes in 2040, where in some cases with assumed low availability of transmission capacities to the surrounding countries a shortfall is observed, so that the Upper Rhine region is dependent on imports. This can be explained by the discontinuation of the previously existing coal-fired power plants. On the other hand, the cases with higher availability of transmission capacities (50 % and 70 %) provide incentives to generate solar power in the Upper Rhine region and export it to the rest of Germany, as the conditions for solar power in the Upper Rhine region are favourable compared to the average solar radiation in the rest of Germany. In 2050, electricity generation exceeds electricity demand in almost all cases considered. It has to be taken into account that in case of a complete conversion of the electricity supply to renewable energies, in principle an electricity generation is needed that significantly exceeds the demand, since in some hours electricity has to be stored in order to cover the demand in hours with a low supply of renewable energies by means of storage. Additional efficiency losses occur when using storage. This is illustrated by the case of complete self-sufficiency of the Upper Rhine region, in which a self-sufficiency level of about 181 % is necessary in the model calculations in 2050.

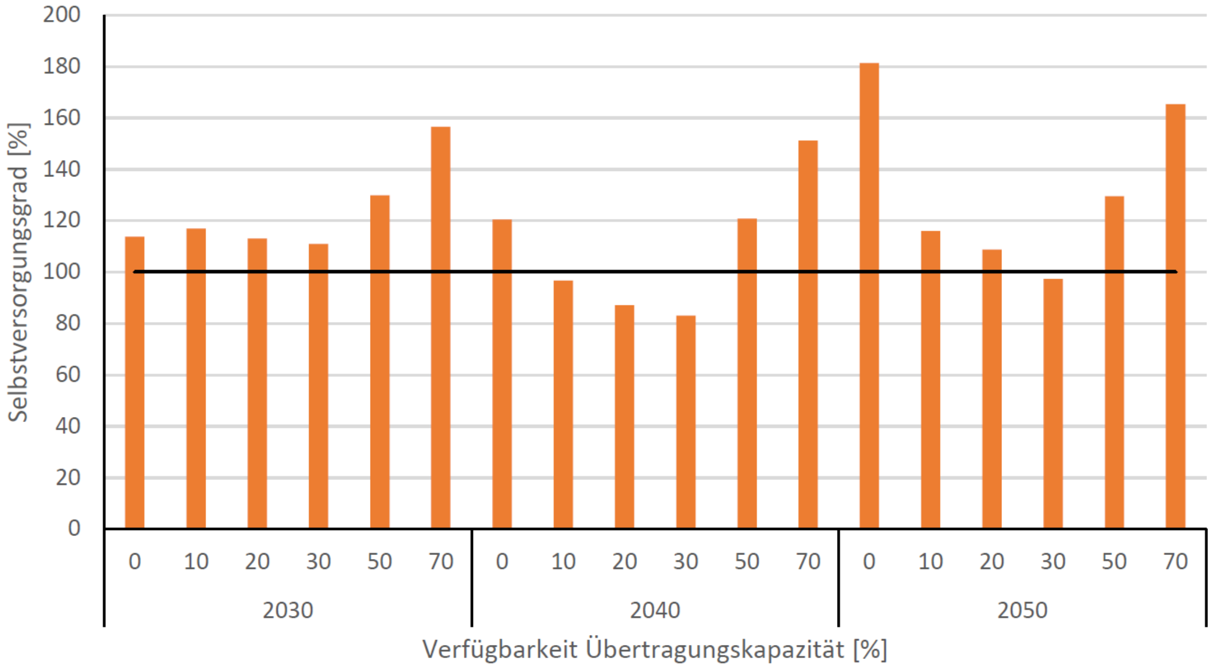


Figure 3.7: Degree of self-sufficiency of the Upper Rhine region with electrical energy under variation of the availability of transmission capacities to neighbouring countries (own calculations)

3.1.2.4 Sensitivity analyses

Cost development power-to-gas

PtG is a crucial component of the transition towards renewable energies in the power grid and is closely related to them. Therefore, the development of the costs of the technology is of particular importance.

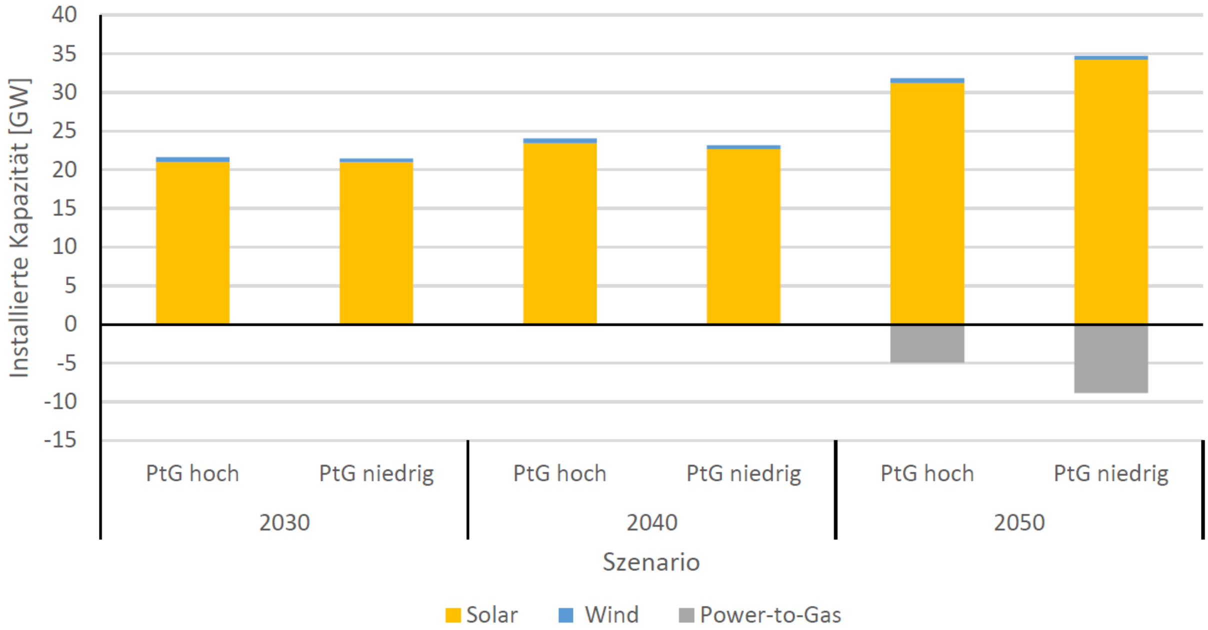


Figure 3.8: Installed capacity of renewable energies and power-to-gas in the Upper Rhine region assuming the availability of 50% of the transmission capacities to neighbouring countries (own calculations)

However, the cost development of technologies for the generation of synthetic gases is characterised by uncertainties. Sensitivity analyses can be used to estimate the influence of these uncertainties on the model results. The results presented above (Figure 3.8) assume an optimistic cost development. Therefore, in a further model calculation, it was examined how higher costs of PtG technologies affect the installed capacities in the model. For this purpose, it was assumed that the investment in PtG in 2050 amounts to 700 €/kW instead of 450 €/kWh in the more optimistic case. For the comparison, the scenario with 50% of the transmission capacity available was selected. The results show that the increased investment required for PtG technologies has an impact on the added capacity (Figure 3.8). In particular, the installed capacity of PtG decreases from about 8.9 GW to about 4.9 GW. Furthermore, the installed capacity of solar plants decreases moderately from about 34.2 GW to about 31.2 GW. In addition, there is a slightly stronger expansion of wind energy in the scenario with higher PtG costs: instead of an expansion to 477 MW in 2050, there is an expansion to 624 MW. The influence of the cost uncertainty of PtG technologies on the systemic economic viability of renewable energies in the Upper Rhine region can therefore be assessed as moderate under the assumed framework conditions.

Electricity demand development

Another uncertainty in the model assumptions arises from the development of demand for electricity. One reason for this uncertainty could be the extent of electrification of transport and industrial processes. Therefore, the sensitivity of the assumptions on the development of electricity demand was examined in a further model calculation. In the baseline scenario, we are guided by the electricity demand assumed in the EU Reference Scenario (Capros et al., 2016). According to the reference scenario, electricity demand grows to about 3700 TWh in Europe by 2050. Due to the uncertainties described, we examine a scenario in which the development is 10% stronger than in the reference scenario. Accordingly, electricity demand in this scenario amounts to about 4070 TWh in 2050 in Europe.

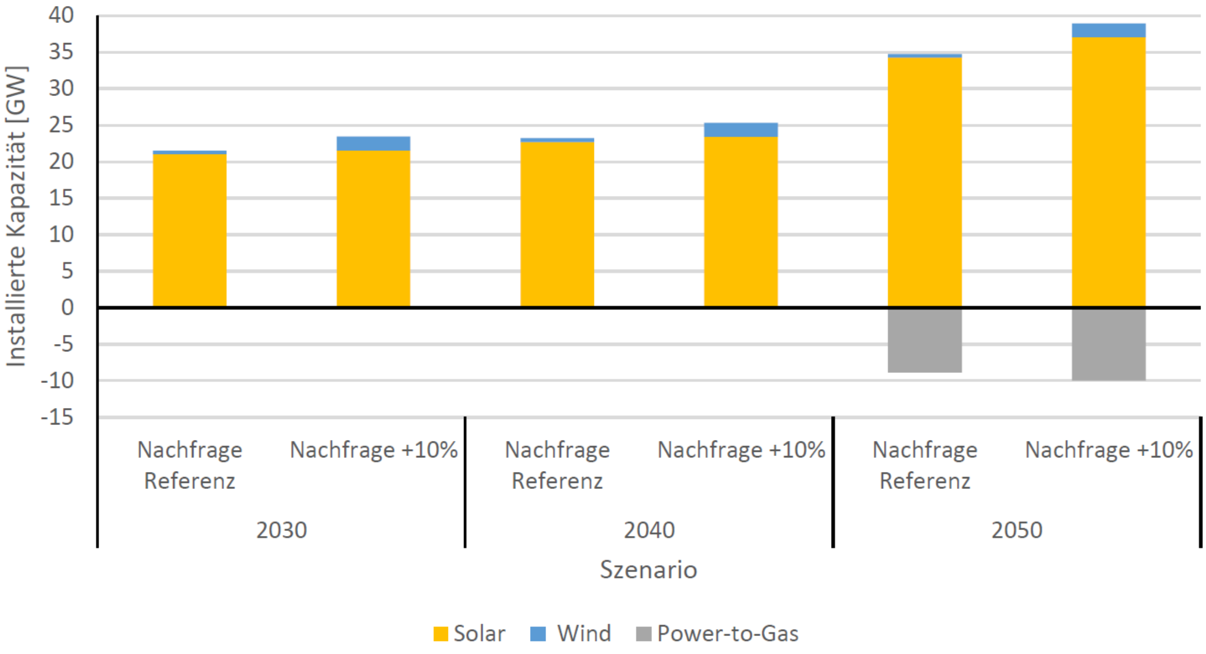


Figure 3.9: Installed capacity of renewable energies and power-to-gas in the Upper Rhine region assuming the availability of 50% of the transmission capacities to neighbouring countries with variation of electricity demand (own calculations)

The results of the sensitivity analysis are shown in Figure 3.9. As expected, there is an increase in the installed capacity of renewable energies. While solar capacities grow moderately from about 34.2 GW to about 37 GW, wind energy experiences a significantly stronger development from 477 MW to about 1.9 GW with increased demand. The strong impact on the installation of wind turbines can be explained by the increased demand also during the night hours in the sensitivity scenario. Considering the increasing market penetration with electric cars, an additional shift of electricity demand towards evening and night hours is possible.

3.1.3 Critical appraisal

In order to classify the results of this study, it is important to discuss key model assumptions. It should be mentioned that the model results can be influenced by factors such as the assumed weather in the respective year, the development of fuel prices, the development of electricity demand or the cost development of PtG technologies. The influence of the latter factors on the model results could be quantified within the framework of sensitivity analyses.

Due to the assessment that biomass potentials in the region are already being used to a large extent, a detailed analysis of biomass expansion was dispensed with. However, technological innovations in this field could lead to additional potentials (Schumacher et al. (Eds.), 2017), which were neglected for the results presented in this study.

Furthermore, the Upper Rhine region has greater potential for the generation of energy from geothermal energy due to its geographical location (TRION-climate e.V., 2019). However, the use of these potentials is controversial in individual cases and fraught with acceptance problems, thus repeatedly leading to regional conflicts. In this project, it was therefore decided not to include the potential of geothermal energy in the model calculations. For a comprehensive evaluation of geothermal energy in the Upper Rhine region, further research is needed that should examine geothermal energy from an economic, ecological, legal and social perspective.

3.1.4 Conclusions

With regard to the expansion of renewable energies, a relatively clear picture emerges from the scenario analyses undertaken in this study. From a systemic perspective, the Upper Rhine region is particularly suitable for the generation of electricity from solar energy. The results of the model calculations vary between about 24 GW and 47 GW of installed capacity.

The picture is different for wind energy. In most cases, the model calculations show only small additions of wind power capacity. This suggests that locations outside the Upper Rhine region offer better conditions for generating electricity from wind power. Via the existing electricity grid, this electricity can be used in the Upper Rhine region. Only in cases that massively limit or prevent the import of electricity into the Upper Rhine region are installations of wind turbines observed. Such cases could occur, for example, due to a delay in grid expansion within the countries. This could lead to the conclusion that additional support for wind turbines in the region will be necessary, should the interest in installing wind turbines in the region increase.

In these scenarios, further storage possibilities for electric power are created in the Upper Rhine region, in addition to the already existing pumped storage power plants. It can be seen that the model calculations favour storage in synthetic gas over the installation of batteries. This could be due to the fact that the existing pumped storage power plants in the region already provide considerable potential for short-term energy storage.

The analysis of price differences showed that a bidding zone in the TMO would probably not increase the efficiency of the European power system. Only in the case that only 30% of the thermal capacities of the new interconnectors to the Upper Rhine market area are available for the market, relevant price differences resulted. However, this assumption must be regarded as pessimistic, especially since future possibilities of grid operation, such as overhead line monitoring, should ensure that line capacities can be better utilised. Furthermore, the EU plans to make 70% of the interconnectors available for trade in order to strengthen the European internal market.

Furthermore, the degree of self-sufficiency of the Upper Rhine region was examined under various assumptions regarding the availability of transmission capacities to neighbouring countries. The results show that even under the assumption of high availability, a considerable amount of electricity is generated in the Upper Rhine region. The results have to be evaluated against the background that a key model assumption is the minimisation of the Europe-wide costs of the energy system. With the exception of the case of full self-sufficiency, the results thus represent a "system-serving" generation of electricity in the Upper Rhine region and do not aim at increasing self-sufficiency in the region. Due to the lack of economies of scale and the nevertheless necessary use of the grid infrastructure, it is controversial in science whether balanced self-sufficiency is a desirable goal for smaller municipalities and communities (McKenna, 2018).

The analysis of the sensitivities of the electricity system to stronger growth in electricity demand suggests that even in such cases wind energy is increasingly used in the region. This could be attributed to increased electricity demand, including at evening and night time hours, and is within the realm of possibility due to the increasing - but uncertain - market penetration of e-cars.

3.2 LEM research

According to a number of studies, Local Energy Markets (LEM) will have a significant impact on voltage violations and congestion. Prosumer demand cycles appear to have an impact on voltage levels, but the magnitude of the impact and whether it is positive or negative depends on the market mechanism used. There is no significant impact on network performance in terms of voltage imbalances and voltage quality when using a mechanism that does not increase the peak demand of the system. It should be emphasised that most studies focused on the development of market models, control mechanisms and subscriber models that had a positive technical impact on voltage, meaning that negative impacts were avoided by design and therefore did not show up in the data.

As phase imbalance in the grid can lead to higher voltage rises and losses, future studies should investigate the impact of LEMs on phase imbalance in more detail, especially as most use cases are focused on prosumers connected to low-voltage grids.

Overall, it has been shown that LEM research is very transdisciplinary, making it difficult to distinguish between the impact on electricity distribution systems and the design of market models or current policy and regulatory frameworks. As a result of our research, we can conclude that research in this area is still constrained by existing market and policy frameworks. In the following, we present the impact of LEM on phase imbalance and voltage at the distribution system level.

3.3 Design of a flexible power grid

For this report, we conducted a thorough literature review to identify and discuss the opportunities for cross-border cooperation at the distribution grid level. While the idea of cross-border interconnection of energy networks has received much attention, much of the current research focuses on the transmission network level. Among all the articles reviewed, a novel method for cross-border interconnection of two distribution networks with a "switch" in terms of system cost saving was presented in (Hunt, 2006). As the interconnection of the distribution networks of the Netherlands and Germany was the first case study for a cross-border interconnection in the EU, the method mentioned in (Hunt, 2006) was implemented within the SEREH project. After the various studies, we assumed that cross-border cooperation in the energy sector can bring benefits at the local level, i.e. at the distribution network level, so that cross-border regions can develop. Following the methodology mentioned in [18], we can present the result of this report as follows.

General assumptions about cross-border regions:

- They are usually less developed in economic and infrastructural terms.
- They can often have complementary characteristics in terms of renewable generation and electricity load
- The most important factor for system cost savings

According to (Hunt, 2006), the results show that especially the complementarity of the two adjacent regions of the considered case study is the source of benefits in terms of system cost savings. In particular, all investigated options of the "switchable element" lead to a reduction of the electricity system costs. However, the level and distribution of the calculated system cost savings and thus the potential benefits for a cross-border CEC depend to a large extent on the type of switchable element connecting the adjacent regions.

Both a "switchable generation plant" and a "switchable flexible consumer" reduce the total costs, but imply that the benefits are unevenly distributed between the two regions. While the "switchable generation plant" brings benefits to the "rural low-load region", the "switchable flexible consumer" brings benefits to the "urban high-load region". Only the "switchable storage" would lead to benefits in the form of system cost savings for both regions, but would also result in the lowest overall benefit. Thus, achieving the highest total cost savings does not correspond to the option where the benefits are more evenly distributed. To solve the problem of unequal distribution between regions, the additional system benefits need to be converted into compensation for the CEC. The CEC could use the benefits to the advantage of the whole cross-border region in the interest of its members and shareholders, thus contributing significantly to cross-border energy cooperation at the local level.

In other words, this uneven distribution of benefits could be mitigated by organising through a cross-border CEC that distributes the benefits to "its members or shareholders or the wider region in which it operates", as required by the provisions on CECs as set out in Directive 2019/944/EU. In this way, the CEC is an organisational tool to distribute the benefits arising from the switchable element more evenly, i.e. for the border community.

The optimisation model developed in the previous research is limited to the economic perspective and therefore not applicable to the planning of the technical implementation, type of power transmission between MVs (AC/DC), technical design of the circuit, dimensioning of cables and cable routes.

The overall results of the model calculation show that the connection of distribution networks via a switchable element, be it a power generation plant, a flexible consumer (electolyzer) or a battery storage, leads to a higher system utilisation and thus to a reduction in system costs.

However, the calculated system cost savings cannot be used as the sole indicator of the economic benefit of such a distribution network. Instead, the results show that coupling regions with complementary electricity generation and consumption characteristics (such as two MS regions in the case study, but this could also apply to two different distribution grids within one country) has the potential to increase (international) electricity transmission capacities in the EU electricity system while reducing the need for additional grid capacity in the transmission grid.

Beyond cross-border regions, the results show that using a switchable element to connect regions with complementary characteristics in terms of electricity generation and demand (e.g. urban-rural or industrial-residential) leads to a better allocation of transmission system capacities and generally to a more efficient system use.

However, the results show that the distribution of benefits is highly dependent on the switchable element and that the choice with the greatest overall benefit is not necessarily identical to the choice with evenly distributed benefits.

This result may help national legislators when incorporating CECs into their regulatory frameworks. It should be noted that CECs should be open to cross-border participation. In addition, CECs should receive financial remuneration for their contribution to system cost savings.

Improved cross-border electricity generation at the local level for the energy transition would require these points to be taken into account when creating a national legal framework for electricity generation. Furthermore, the cross-border operation of CECs could help to strengthen fundamentally weak border regions.

3.4 Decision Support Tool and its application in the implementation of energy strategies

A wide variety of technologies (such as solar photovoltaic or thermal panels, nuclear, gas, or coal power plants, hydro dam turbines, etc.) can be combined to produce energy. The most widely used energy planning models nowadays employ an approach of estimating the cost of each possible scenario and then selecting the one with the lowest cost. These costs consider the overnight investment required to purchase and implement the technologies to exploit the resources, and the operation and maintenance costs. In the case of controllable resources, the costs of fuels consumed are involved in the estimations. Environmental impacts are considered through specific additional costs that affect some technologies more than others, such as the carbon tax, for example. This approach based on cost optimization has the disadvantage of focusing on a single scenario (that of minimum cost), which leaves the user with too little visibility of other possible options. This is a major handicap insofar as the estimation of the costs of the scenarios is subject to great uncertainties.

The costs of the technologies can indeed vary greatly over time and these variations can be very different from one technology to another. However, the prices of fuels such as oil or gas evolve in an erratic way according to the available quantities, the demand on the energy markets or the stock market speculation. For this reason, it is impossible to accurately predict the cost evolution of fossil fuel technologies. For other technologies, the trends are clearer. For example, the costs of nuclear power plants are regularly revised upwards because of the increasingly precise assessment of the cost of their dismantling, as well as the costs of treating and storing their waste. On the other hand, the costs of wind turbines, photovoltaic panels, and certain storage technologies such as batteries are falling exponentially because they are being produced in ever greater quantities, which makes it possible to optimise their manufacturing processes. These costs probably do not yet consider the exact costs of dismantling and recycling these technologies at the end of their life cycle, as well as the costs of the raw materials they are made of (such as rare earth and metals), which are likely to become scarcer in the future.

No one is currently able to predict precisely how long these trends will continue. Thus, the cost is certainly an indispensable indicator for guiding energy strategy choices, but it is not reliable enough to exclude options simply because they are more expensive.

The REPM (Regional Energy Planning Model) method does not aim to select only the less expensive energy option but to describe, in the simplest and most complete way possible, the different possible options. It consists of: 1) evaluating the hourly characteristics of the energy demand of the region under consideration; 2) evaluating the resources potentially available in the region under consideration; 3) estimating the technical characteristics of different scenarios based on the introduction of intermittent energy sources (solar and wind) as a percentage of the final electricity demand; 4) grouping the scenarios with similar characteristics into clusters; 5) estimating the costs of energy production for each cluster of scenarios by considering the different technologies that could exploit the resources selected in each cluster of scenarios. The method is able to provide a list of scenarios (each scenario being the representative of a cluster) whose characteristics will be sufficiently different so that decision-makers can easily select the option that seems best to them.

3.4.1 REPM storage and controllable sources management algorithm

The REPM (Regional Energy Planning Model) starts from an estimation of the hourly electrical demand to be satisfied, then varies the solar and wind energy production within the limits available on the region considered. Combining the hourly electric demand and the hourly solar and wind energy production it computes the required hourly storage and additional energy supplied by controllable sources. Finally, the model estimates the energy which could be exported from the region in case of overproduction (Figure 3.10).

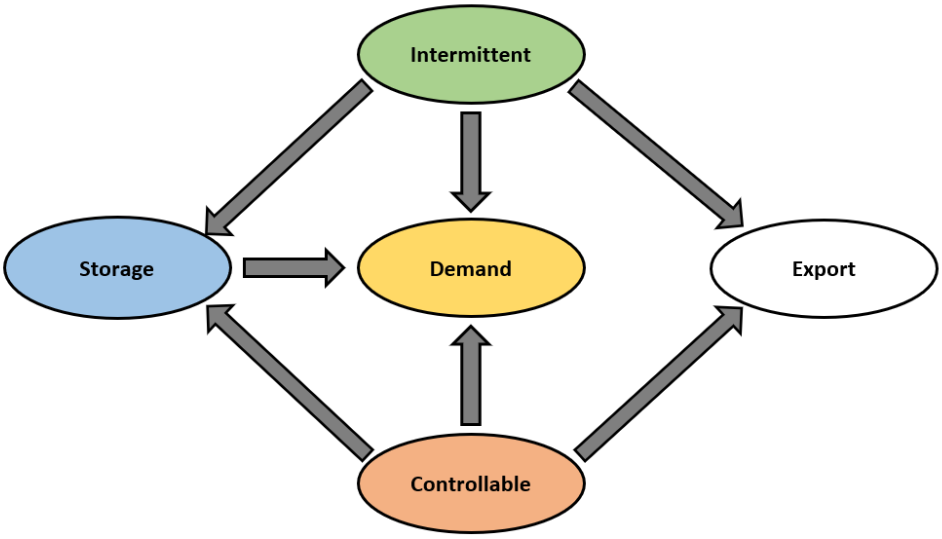


Figure 3.10: Energiesystemdiagramm des REPM-Model

REPM computes, each hour, the residual energy (R) which remains to be supplied when solar and wind energy are introduced into the electric mix (Figure 3.11).

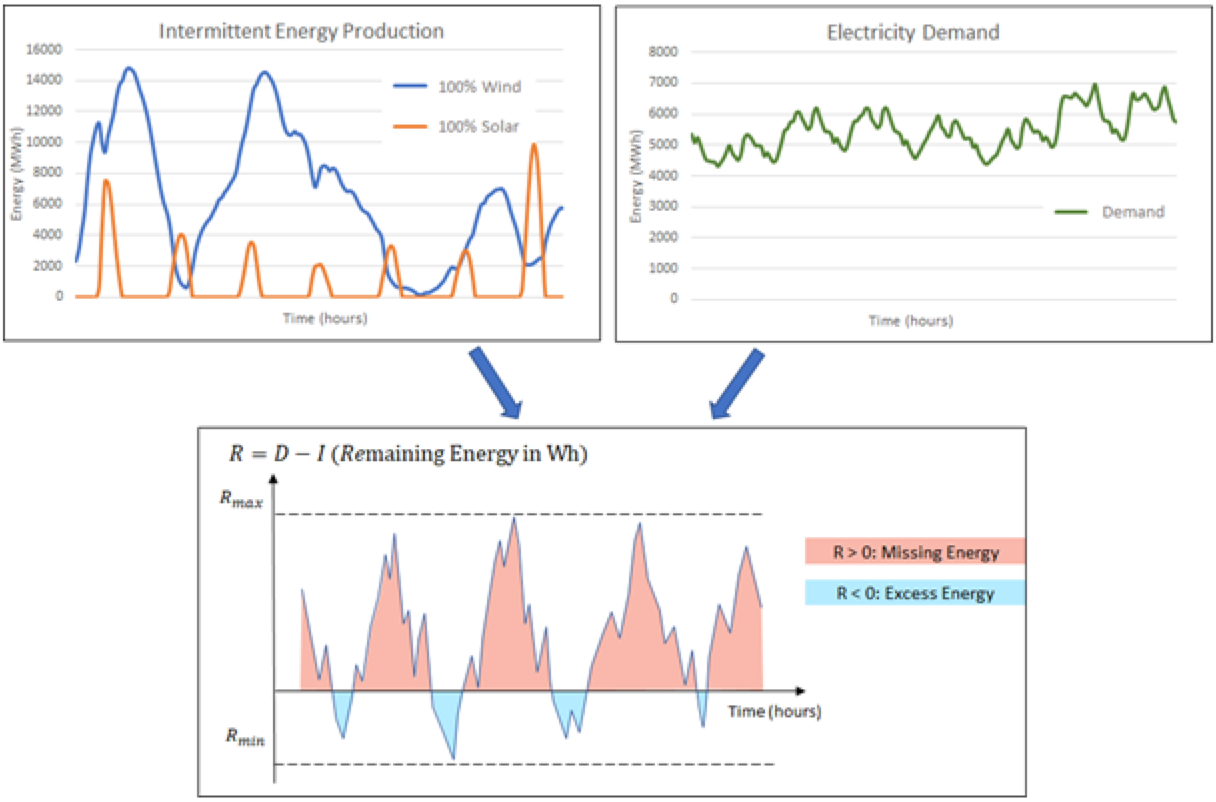


Figure 3.11: Calculation of the residual energy (R) performed each hour by REPM from the hourly energy demand (D, MWh) and the hourly intermittent energy production (I, MWh)

The hourly residual energy is used to compute the time evolution of the energy stored using two different alternatives named: “Direct release method” and “Peak shaving method” (Figure 3.9). In both cases, energy is stored when the demand is lower than the amount provided by the solar and the wind ($R < 0$) and released when the demand requires more than the solar and wind supply ($R > 0$). Energy is stored until the maximum storage is reached ($DS = S_{h+1}$ –

S_h the hourly storage variation is equal to R but within the constraint: $0 < S < S_{max}$). When the stored energy is no longer available because it has been depleted (S=0), REPM provides the missing energy using a controllable energy source (C = R). With the "Direct release" algorithm, the maximum storage capacity (S_{max}) is defined by the user and the energy is released as soon as the residual energy is positive (Figure 6-left). The "Peak Shaving" algorithm handles storage a little differently. The user chooses the level of cut-off of the residual energy peaks, which corresponds to the maximum capacity of the controllable sources (C_{max}). The stored energy is only released at the time of the residual energy peaks. The maximum storage capacity is adapted to compensate for the energy to be released at peak times (Figure 3.12 right).

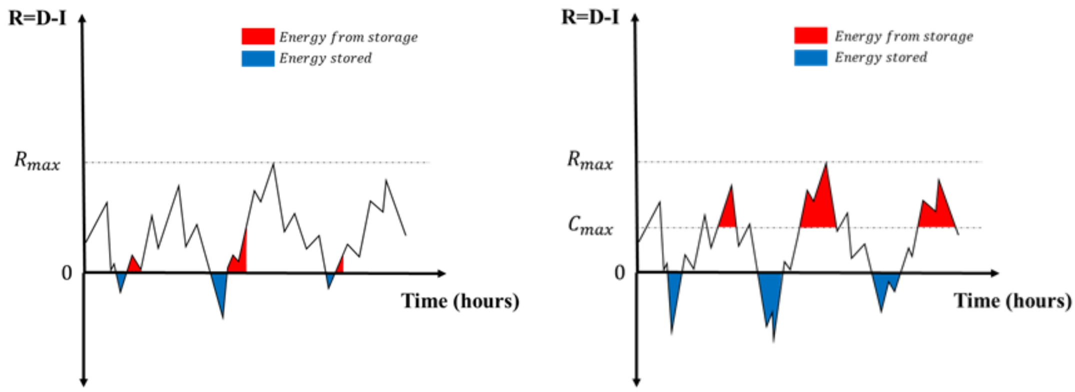


Figure 3.12: Load duration curve of residual energy (R = D - I) calculated by the REPM model to distinguish different alternative to manage the energy storage : Direct release (left), Peak Shaving (right)

Figure 3.13 shows the main differences that occur when using the two different alternatives to manage storage. With the "Peak Shaving", the capacity of controllable sources decreases as the amount of intermittent energy introduced into the electricity mix increases. It reaches zero when intermittent energy fully satisfies demand and losses (about 110% of demand). The stoking increases as more intermittent energy is introduced into the mix. It reaches a maximum when intermittent energy fully satisfies demand and losses. After that, it decreases, showing that the overproduction of intermittent energy can compensate for the need for storage. Note that below 20%, there is no need for storage, energy is never overproduced, because demand is always higher than intermittent production. "Direct release " shows the same trends as "Peak Shaving", but since this method is not designed to peak-shave, it is unable to decrease the capacity of controllable sources before intermittent sources meet all demand. On the other hand, while this method requires more capacity at controllable sources, it requires less capacity for storage.

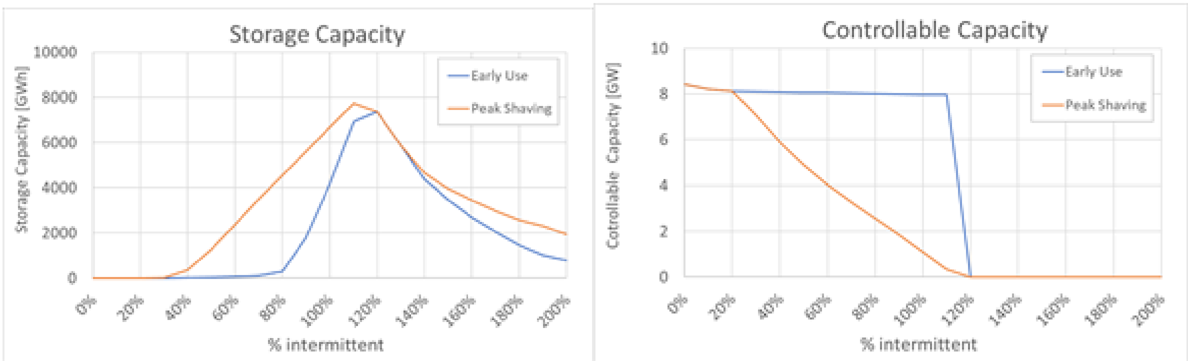


Figure 3.13: Storage capacity (left) and controllable capacity (right) vs. the amount of solar and wind energy introduced into the electricity mix (expressed in percentage of the electric demand) for the "Direct release" (blue curves) and "Peak Shaving" (red curves) algorithms

3.4.2 Results: REPM scenarios generation

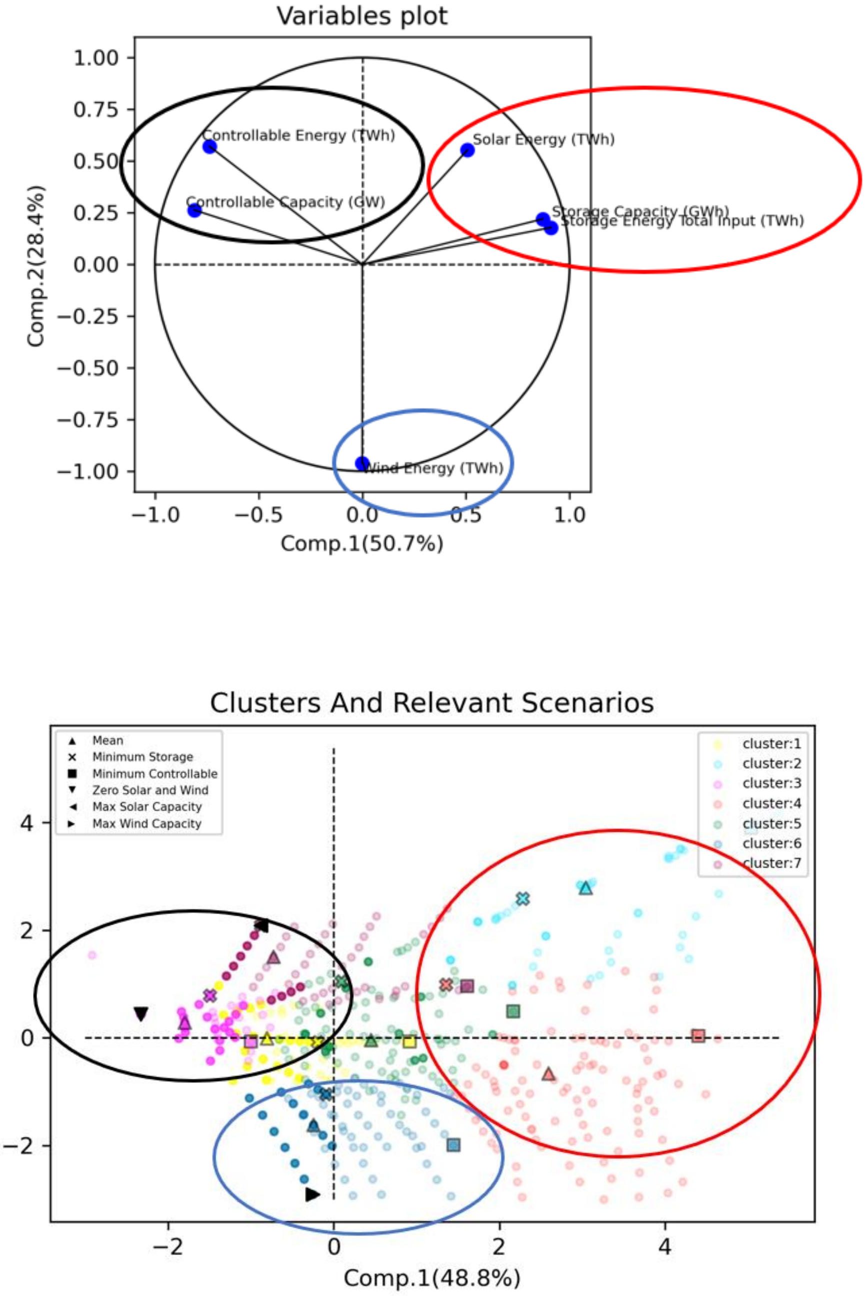
REPM is used to generate a set of possible scenarios by evaluating the storage and controllable energy characteristics resulting from varying the introduction of energy produced by the intermittent sources. The repartition between solar and wind sources within the intermittent share is also evaluated for a range going from 0% solar (100% wind) to 100% solar (0% wind).

Scenarios' characteristics are generated using the two storage management methods "Direct release" and "Peak-Shaving" but also by varying the parameters specific to each of the two methods such as the maximum capacity of storage and controllable sources.

As a result REPM generates a large number of scenarios each one with its own characteristics that influence their costs, e.g., the capacity and energy produced from intermittent sources (wind and solar), controllable sources, and storage.

A methodology was developed to present all the scenarios and summarise their main characteristics. In the first step, a Principal Component Analysis (PCA) is used to underline the correlations between the different characteristics of the scenarios. It shows that the scenario characteristics can be well summarised by only two components, i.e., two axes (Figure 3.14-a). Along the first component (horizontal axis) the scenarios using an important amount of controllable resources (left) are opposed to those importantly using storage (right). Along the second component (vertical axis), scenarios using more solar energy (up) are opposed to those using more wind energy (down). In the second step, the K-Means clustering method is used to group scenarios with relatively similar characteristics. The graph in Figure 3.14-b presents the different scenarios using the two PCA components and shows the distribution of the 7 clusters that are distinguished by different colors. The clusters on the left of the graph contain scenarios that use a lot of controllable sources, while those on the right use a lot of storage. Clusters at the top of the graph use more solar energy while those at the bottom use more wind energy.

Within each of the resulting clusters, a representative scenario of the cluster is selected (mean scenario), and the ones with extreme values in the group (i.e. the scenario with the minimum storage and controllable capacity, maximum solar and maximum wind capacity, and the mean scenario), as well as the scenario “zero” which corresponds to the scenario with zero capacity of solar and wind energy, and therefore zero storage capacity. This set of scenarios within each cluster is called “representative scenarios”.



a)

b)

Figure 3.14: Analysis of the resulting scenarios from REPM: a) representation of the correlation of the resulting scenarios with the components 1 and 2 of the PCA as axes, and b) projected location of the resulting scenarios on the PCA components 1 and 2. Black circles correspond to scenarios characterised by large controllable capacity and energy, blue circles to scenarios with important wind capacity, and red circles to scenarios with important solar and storage capacity.

3.4.3 Results: Cost evaluation of REPM scenarios

The total annual cost (TAC) of each scenario is evaluated considering the investment, fixed, variable and fuel costs:

$$TAC_t^{(s)} = IC_t^{(s)} * (AC_t + FC_t) + EP_t^{(s)} * \left(VC_t + \frac{FUC_t}{\eta_t}\right) \quad (1)$$

where,

- $IC_t^{(s)}$ is the installed capacity in MW,
- AC_t is the annualised capital cost in \$/MW/yr, i.e. the initial investment of the infrastructure amortised over its estimated lifetime,
- FC_t is the annual fixed costs in \$/MW/yr, which corresponds to the costs of operating the system over a year and includes staff costs, insurance, taxes, repair, or spare parts,
- $EP_t^{(s)}$ is the annual energy production in MWh/yr,
- VC_t is the annual variable costs in \$/MWh/yr, which includes expenses related to the variation of the mean capacity factor of the system, e.g. contracted personnel, consumed materials, and costs for disposal of operational waste per year, excluding fuel costs,
- FUC_t is the cost of fuels consumed for electricity production in \$/MWh/yr, used with the fuel usage efficiency η_t.

AC_t is calculated based on the overnight capital costs of the technology “t” (CC_t) in the energy mix in \$/MW, the lifetime “l” in years, and the discount rate “r” :

$$AC_t = CC_t * \frac{r * (1 + r)^l}{(1 + r)^l - 1} \quad (2)$$

r is supposed to consider the depression of the money as well as the value of the technology t over time. A r value of 5.77% is used for the analysis of energy strategies based on the values reported in published studies.

The costs of storage, are computed with a zero value of FUC_t/η_t (since no fuel costs are associated with storage) and $ES_t^{(s)}$, the annual energy stored in MWh/yr :

$$TAC_t^{(s)} = IC_t^{(s)} * (AC_t + FC_t) + ES_t^{(s)} * (VC_t) \quad (3)$$

The AC_t of storage is calculated based on the number of utilisation periods (np, in years of using the storage infrastructure) :

$$AC_t = CC_t * \frac{r * (1 + r)^{np}}{(1 + r)^{np} - 1} \quad (4)$$

"np" is taken as the minimum between the lifetime of the storage technology "l" and the ratio between the yearly cycles of storage and the use-life cycles :

$$np = \min\left(l, \frac{simulated\ cycles}{use\ life\ cycles}\right) \quad (5)$$

The total annualised costs of scenario "s" ($TAC^{(s)}$) is obtained as the sum of the $TAC^{(s)}$ for all technologies.

Figure 3.15 shows the cost evaluation in a rather simple situation where the energy of the controllable is provided entirely by combined cycle gas turbines (CCGT), the storage by large concrete towers and the intermittent energy by wind turbines and photovoltaic solar panels. The graphs are plotted for the less costly scenarios of each cluster (including the scenario zero which uses no intermittent sources.

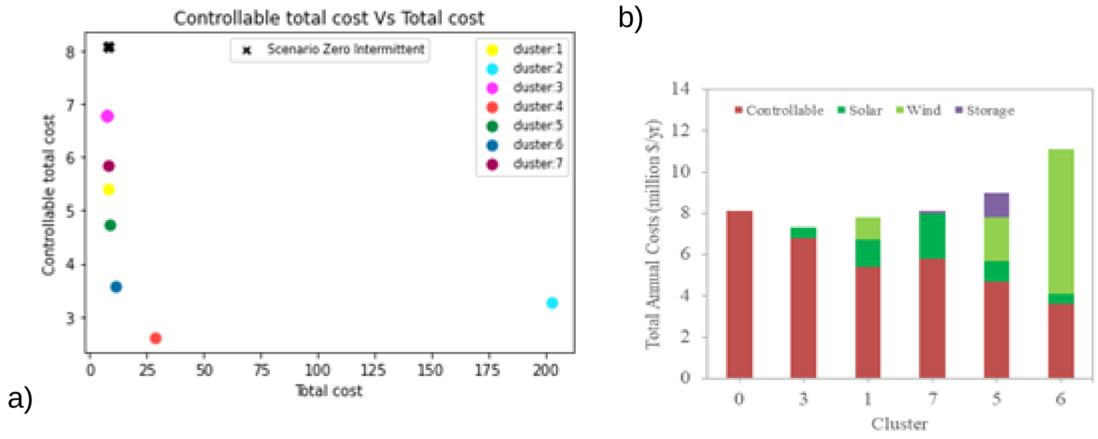


Figure 3.15 Costs of controllable and total costs for the scenarios with the less TAC within each cluster, and the scenario of zero intermittent in the system, using as technologies of reference horizontal axes wind turbines and photovoltaic solar panels for the intermittent energy sources, and for the controllable and storage, combined cycle gas turbines (CCGT) and large concrete towers. The costs are expressed in billion US Dollar per year

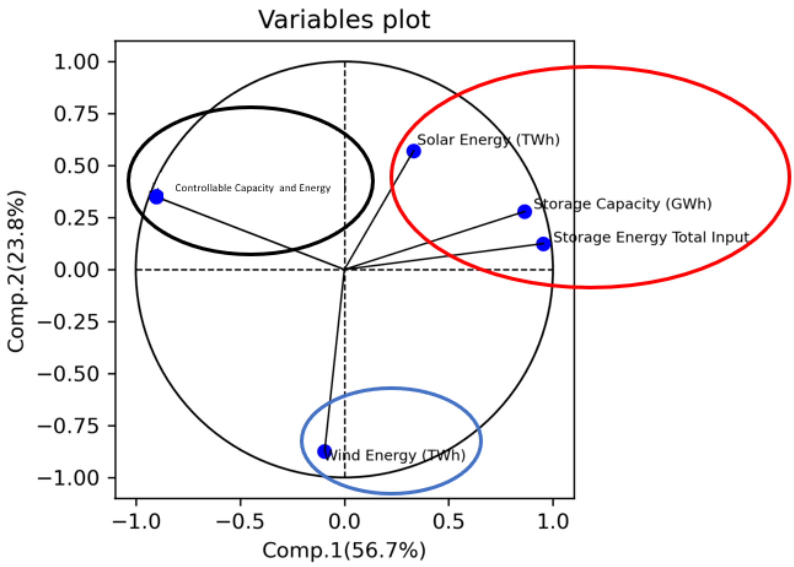
Figure 3.15-a shows the total annual cost of cluster 4 and 2 is significantly higher than the other clusters. These two clusters use a large amount of solar energy and require large storage capacities (Figure 3.14). Due to their prohibitive total cost, they do not appear on the graphics of Figure 3.12-b which shows the repartition of the costs between the controllable, solar and wind sources and the storage for the cheapest scenario of each cluster. The cost of controllable resources decreases as more and more energy is produced by intermittent resources. The total annual cost becomes more expensive than scenario 0 when a large amount of intermittent resources is introduced into the mix (clusters 5 and 6). In such a situation the model finds that more wind energy is required than solar energy.

3.4.3 Results: PERSEUS scenario versus REPM scenarios

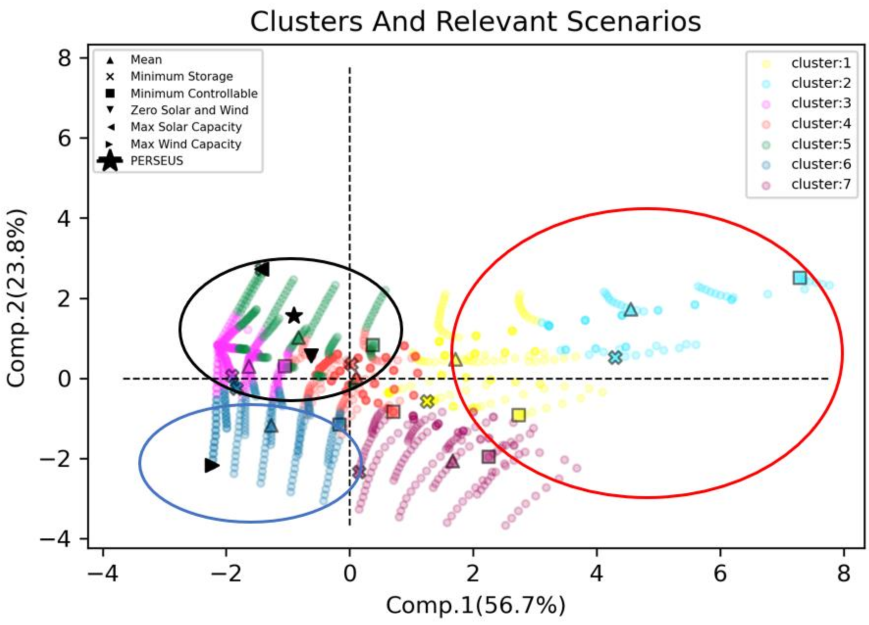
The REPM allows modelling different scenarios while PERSEUS results correspond to one scenario with very specific conditions of energy storage. The PERSEUS scenario was simulated and included in the projection of the REPM resulting scenarios (Figure 3.13). We used the developed methodology based on the PCA and K-Means methods to map the location of the PERSEUS scenario relative to the set of resulting scenarios from REPM.

PERSEUS scenarios are located in the black circles, in the upper-left part of Figure 3.13. This means the scenario found by PERSEUS has important controllable energy production, i.e., it keeps the total or most of the controllable installed capacity, and the intermittent share relies on solar rather than on wind. Compared to the REPM resulting scenarios, PERSEUS uses less storage capacity.

Differences were found in the storage management method. REPM uses the storage for a controllable peak-shaving purpose. Applied to an energy system based on nuclear energy, it can help to reduce nuclear capacity needs. We noted that in the PERSEUS model, if there is no need for peak-shaving, the storage system can be operated whenever it is needed and within the limits of the capacity allowing a higher frequency of utilisation (larger number of cycles). In this way, additional economically optimised scenarios using storage could be considered. With fewer storage restrictions, the lowest costly REPM scenarios use less controllable energy and tend to reduce storage by increasing wind production at the expense of solar production.



a)



b)

Figure 3.16 Comparison between PERSEUS and REPM results: a) representation of the correlation between the scenarios and the components 1 and 2 of the PCA, and b) projected location of the clusters and resulting scenarios on the PCA components 1 and 2. Black circles correspond to scenarios characterised by large controllable capacity and energy, blue circles to scenarios with important wind capacity, and red circles to scenarios with important solar and storage capacity. Representative scenarios of each cluster are included. The projection of the scenario corresponding to the results of the PERSEUS model is represented, it is located in cluster 5 within the black circle. Plotted scenarios correspond to: γ = 100% & ηStoToDem = 40%. The demand used as input for REPM corresponds to the same profile used for PERSEUS

3.4.4 Conclusions

The energy balance of the Upper Rhine region is heavily dependent on imports of fossil resources. A new methodology has been tested in the framework of the RES-TMO project to evaluate how local renewable energy production strategies could meet 100% of the electrical demand of the Upper Rhine region. The calculation of the wind and solar energy production potentials in the Upper Rhine Region shows that these potentials are sufficient to meet 100% of the electrical demand, or even more. A large set of scenarios have been designed varying the amount of intermittent energy sources (solar and wind) introduced into the electricity mix and computing the storage and controllable energy needed to fulfill the energy demand.

The scenarios were sorted into clusters. Then, a set of technologies have been associated with each scenario to compute the total annual cost of each scenario (one technology used to produce the controllable resources and another one for ensuring the storage). The cheapest scenario has been chosen as the “representative scenario” of each cluster. The results have shown that the cost of controllable resources decreases as more and more energy is produced by intermittent resources. The total annual cost of the scenarios becomes more expensive than the scenario using only controllable sources when a large amount of intermittent resources is introduced into the mix. In such a situation the REPM model finds that more wind energy is required than solar energy. It is however important to note that the REPM model focuses only on URR regional energy production with no consideration of potential energy exchanges with other regions yet. The analysis of the different possible scenarios still needs to be improved by introducing the possibility to consider a set of technologies for the production of controllable energy as well as for the storage.

Chapter 4. Work Package 7: Data Security in Smart Grids in TMO

4.1 European Rules for the Security of Energy Data

The European Commission is laying out plans to create a new Joint Cyber Unit to combat the escalating number of significant cyber events. These are affecting public services, enterprises, and citizens throughout the EU, and are increasing in quantity, scale, and impact. Addressing these serious threats to our security therefore requires advanced and coordinated responses in the field of cybersecurity. The EU has attempted to address this through, amongst others, the EU Network and Information Security (NIS) and the General Data Protection Regulation (GDPR) Directives.

All relevant EU actors must be ready to respond collectively and disclose pertinent information based on a 'need to share' rather than a 'need to know' premise. In the power value chain, governments, utilities, and other stakeholders must be proactive in their search for solutions to evolving cyberthreats. This can be supported by a long-term commitment to cooperation and partnership.

In practice, this means coordination between Member States is vital in order for them to be compliant with the NIS directive. This requires not only cooperation nationally between the single point of contact of each Member State and the Computer Security Incident Response Teams (CSIRTs), but also among Member States' governments and enforcement agencies.

Smart application functionalities are not clearly framed in official norms that usually define and impose quantifying criteria in terms of technical specifications. This is why working and elaborating on the standardisation enclosure, especially for the most affiliated pieces of the smart grid, becomes an urgent need.

However, directives – the EU's legal instrument – have an inherent weakness, as they must be implemented in each Member State's national legislation. This unavoidably causes further difficulties in creating a harmonised and high common level of security of network and information systems across the EU.

There is thus a need for a more coordinated approach to crisis response so that Member States promptly share relevant critical information with each other. Equally important is that alignment and consistency of messages to the public takes place resulting in containment of the damaging impacts of cyber-attacks.

In conclusion, the NIS Directive is viewed as a baseline for the cyber security of critical infrastructure with a focus on measures such as the establishment of CSIRTs inside Member States and their coordination through a CSIRT network. Any additional regulation should build on and complement the frameworks created by the NIS and GDPR Directives.

4.2 Survey Responses of Electricity Network Operators

This work was supported through survey responses based on several individual interviews with representatives of key energy companies from the Upper Rhine Region (URR), as well as stakeholder workshops with electricity network operators. These helped to clarify their attitude towards energy decentralisation in terms of regional energy resilience via distributed renewable energy resources (small to medium scale renewable generation) and their concerns, anticipated challenges, future plans and development perspectives.

The power system transition to smart grids poses challenges to the development of electricity distribution networks. As accounting for stakeholders' and actors' market interests is essential to successfully upgrade the electricity network, their opinions and experiences can provide particularly valuable insight for policymakers. This is especially the case when it comes to technological issues linked to the integration and use of distributed energy resources (DERs), as well as network optimization and security (Sirviö et al., 2021).

To improve the cyber resilience of electricity systems, policymakers must first raise awareness and collaborate with stakeholders to continuously identify, manage, and communicate emerging vulnerabilities and hazards. Policymakers are also in a unique position to foster cross-sector collaboration, organise information exchange programs, and support research initiatives in the electrical industry and beyond. Ecosystem-wide collaboration can aid in better understanding of the dangers that each stakeholder poses to the ecosystem, as well as vice versa.

There is a plethora of risk management tools, security frameworks, technical solutions, and self-assessment methodologies to choose from. Policymakers and business leaders must use what is relevant in their situation and view resilience as an ongoing process rather than a one-time event. Both policymakers and industry should commit to a collaborative approach based on constant conversation.

While complete prevention of cyberattacks is impossible, electricity systems can be made more cyber resilient by designing them to withstand shocks and be able to quickly absorb, recover, or adapt, all while maintaining the continuity of critical infrastructure operations, or at least a large part of it. It's crucial to be able to adapt to new technology, as well as new hazards and threats.

Governments all across the world can improve cyber resilience through a variety of policies and regulations, ranging from highly prescriptive to framework-oriented, performance-based methods. More prescriptive approaches have the benefit of allowing for more efficient compliance monitoring, but they may struggle to keep up with developing cyber threats. Less prescriptive, framework-based approaches allow for diverse approaches and implementation speeds across jurisdictions, but also raise challenges about how to develop a coherent and strong cross-border cybersecurity approach that has a demonstrable and effective impact. While taking into account the global character of risks, implementation techniques should be adjusted to national situations (Marron et al., 2019).

Because of the global and fast nature of the internet, international cooperation is especially vital — an attack on a single asset can quickly spread across the globe. International organisations and policymakers play a critical role in fostering international collaboration. Collaboration across all key stakeholder groups, from policymakers and regulators to individual utilities and electrical equipment providers should be a priority.

A survey of 947 organisations identified as Operators of Essential Services (OES) and Digital Service Providers (DSP) was conducted in November of 2021 across the 27 Member States (European Union Agency for Cybersecurity, 2021). Just under half of the respondents pointed to a significant positive impact of the EU Network and Information Security (NIS) Directive. The survey also found that the vast majority of respondents consider that their information security controls meet or exceed industry standards.

However, from a financial point of view most of the participants (67%) have stressed the fact that the execution of the NIS Directive necessitated a separate budget, estimated at a median cost of EUR 40 000, or the equivalent to 5.1% of their overall information security budgets besides requiring additional full-time employees.

4.3 Predictive Models of Data Security Vulnerabilities in the TMO

Over the last decade, energy infrastructures, particularly electricity infrastructures, have undergone significant changes, characterised by the shift from a system in which fossil-fuel-based generation adapts to user consumption to one in which different types of users – generators, consumers, and those who do both – are managed. (Canaan et al., 2020)

Another development is the vast digitization of the entire infrastructure in order to optimise, remotely supervise, and monitor an ever-more complicated system. Furthermore, to meet global energy demand growth and climate change, there is a growing need for energy efficiency and optimization. Demand-response services are offered to users to help them save energy by allowing them to optimise their use, such as by reducing or changing their electricity usage during peak periods. These services rely on networked smart devices, such as sensors and actuators, that are extensively used in homes to monitor energy usage and limit energy equipment consumption to avoid overload. These smart devices, often known as the Internet of Things, are expected to number in the billions in the coming years. The benefits of this change are expected to include a more cost-effective, long-term, and reliable energy source. (Canaan et al., 2020)

Meanwhile, energy systems are becoming increasingly vulnerable to cyber-attacks. Because of the widespread use of ICT (Information and Communication Technologies) and new data interfaces such as new and connection-oriented meters, collectors, and other smart devices, the attack surface is expanding, providing new ports of entry for attackers. Furthermore, energy systems are high-impact targets for attackers, such as causing large supply disruptions or obtaining critical information. The increasing amount of private sensitive consumer data available to service providers, utilities, and third-party partners can potentially be a motivator for cyber-attacks. The energy sector looks to be one of the three most impacted sectors with the greatest incident costs, according to a research published by ENISA (The European Union Agency for Cybersecurity) in August 2016 measuring the cost of cyber security incidents affecting vital information infrastructures. (Canaan et al., 2020)

4.4 Recommendations on Trinational Protection Against Cyber Attacks to Enhance Energy Security

In comparison with the partly robust power conventional system, research into security enhancement of the electrical power data system is in its infancy, with many unidentified security vulnerabilities.

The complexity level of the actual power networks and the critical role that it plays in every domain form a double-edged challenge, especially when a newly introduced technology might itself be the source of threat.

Electricity systems work in real-time, with availability and reliability taking precedence. Electricity industrial control systems must react in fractions of a second, necessitating the use of cybersecurity processes such as authentication to ensure that the underlying industrial control system functions run smoothly. Because of the real-time nature of electricity, basic cybersecurity operations such as patching and rebooting are more complicated than those done on less critical situations, which are easy to pull out of service for a short period of time.

Similarly susceptible to cascading effects, electrical systems can be subjected to assault spreading across their digital and physical systems. An outage induced in a particular part of the system could cause problems elsewhere and a single event, as with other energy security issues, can cascade across the whole electricity network, resulting in widespread disruptions.

The design and deployment of CPS (Cyber physical system) and IoT (Internet of things) are at a crossroads. A wide range of new devices has been enabled through advances in networking, processing, sensing, and control systems. These technologies are being created and deployed right now, but security is frequently put off until later. Functional requirements and fast-moving markets drive industry and design trends to change quickly, and standards are only now beginning to emerge. Because many technologies already in use have life spans measured in decades, current design choices will have an impact on the transportation, health care, building controls, emergency response, energy, and other sectors over the next decades.

New types of communication and data-management systems must not just handle the different emerging media trends and smart equipment (e.g. computer-based or microprocessor-based), but they also need to cope with existing legacy systems in a manner that is adjustable to scalability and above all, resistant to cyber intrusion. To this end, smart grids have to come as a complementary solution and not an eliminating or excluding one. These technical uncertainties, plus the additional investment costs, have evoked the political reluctance practised by energy operators against this shift.

Europe has been working on energy transition and smart grids since 2005, starting by creating the smart grid technology platform. There were also several initiatives that developed experimental testbeds for smart grids solutions, which aimed to highlight the most critical challenges and potentials accompanied by this evolution and their influence on the European power systems. Nevertheless, a further and more holistic analysis that is based on a profound technical understanding of each individual system architecture and basically includes the impact of both social and economic aspects on such heterogeneous systems, is yet to be accomplished in order to be able to trade-off between the existing approaches and pilot experiences, choosing a unique and valid experience that is suitable to be scaled up and replicated.

On the other hand, a very promising approach to overcome the majority of previous issues appears through energy communities, in which current grid problems are managed in a coordinated way such that avoiding costly network reinforcement along with maintaining aspired values of the smart grid. That is why we might be able to envisage the future smart grid as a sort of aggregation of multiple integrated entities or microgrids supervised, monitored, and controlled via a reliable communication-based layer. Accordingly, the increasing interest in microgrid development as the core of the smart grid systems is completely justified, although this increasing interdependency between physical and nonphysical power system components, which forms the so-called cyber-physical systems, raises a whole new level of complications.

The work on the smart grid application, in general, lacks approach intersections, and is still being dealt with from separate domains in the research world. Although using the microgrid model to carry out experiments on the cyber-physical security has plenty of practical justifications attributed to the important role it plays in paving the way towards smart grids, regional resiliency, and the facilitation of the introduction of small medium scale renewable generation units, the microgrid's context was mainly consulted owing to the relative simplicity in capturing and recording interventions, either as an injected attack or control modification. For example, the "islanded microgrids" broached by a fair number of papers, especially the DC type, have unarguable merits in terms of autonomy. However, this will only leave us with specially tailored methods and solutions that do not necessarily fit all cases. This reflects the high level of complexity needed to carry out experiments and designing testbeds that correspond to the actual topology of the smart grid. Not to mention the unwillingness of grid operators to publicly share any sort of data that might have the potential of tampering the integrity of their systems.

On a larger spectrum, cybersecurity measures for energy systems still come as accessories and not as a built-in function. In particular, for most of part, the electricity-related equipment that gets evolved at an exponential rate makes it extremely difficult for cyber defense mechanisms to keep pace with this development in the absence of up-to-date standards and common market trends. At least, securing the smart grid requires a multidisciplinary approach, and economic and social development are usually forgotten or neglected aspects of this process. Even the most remarkable technology inventions are useless without being approved by clients.

Then again, embedding a culture of cyber hygiene and implementing risk management strategies for a cyber-resilient application of the intensified digital modern life is extremely critical across all sectors, the energy system included, with a growing need for sector-specific characterization methods.

Finally, human competences that acquire relevant knowledge to address cyber security in the energy sector and promote research within the energy industry have to be a strategic priority to be worked on in Europe.

III. Summary of the Main results of the Analysis of the Socio-Cultural, Regulatory and Economic Frameworks

Chapter 5. Work Package 4: Analysis of Socio-Cultural Conditions and Integration of Stakeholders' Views

The work package 4 (WP4) studied the socio-cultural conditions (Baggioni *et al.*, 2019) for the development of a renewable energy system in the Upper Rhine region (Hamman & Vuilleumier, 2019 for an overview; Pohn, 2016, dealing with the anti nuclear movement in the Upper Rhine), in order to better understand the conditions required for key players (e.g., energy suppliers, network operators, associations) to work together across national borders, as well as the acceptability of social innovations involving citizens (Bally, 2015; Bauwens *et al.*, 2016; Assié, 2021) in the local production of renewable energies (Christen & Hamman, 2015a, 2015b; Pellegrini-Masini, 2020).

Figure 5.1: A map showing the key players in the public and private sectors in the TMO region

Regarding our main results, European policies all consider that increasing the share of renewable energies in the energy mix is a prerequisite to the decarbonisation of energy systems in order to achieve climate policy objectives (Evrard, 2013 ; Christen *et al.*, 2014; Bafoil, 2016). EU member states have in particular committed to reducing carbon dioxide emissions by 80% by 2050. Despite this common goal, all countries are moving towards it at different speeds.

Renewable energy has very different shares of the electricity mix in France (24.1%), Germany (45.7%) and Switzerland (61%) both overall and in terms of the energy sources used (the graphs are presented below):

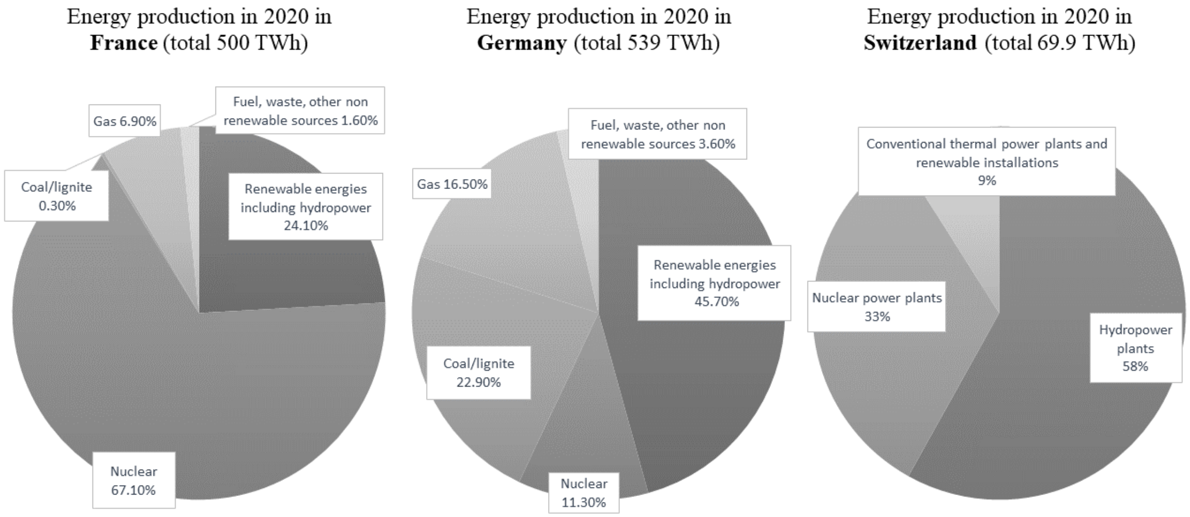


Figure 5.2: Net electricity production in 2020 in metropolitan France, Germany and Switzerland, © Sophie Henck, UMR SAGE, 2022 (See: https://allemagne-energies.com/bilans-energetiques/ ; and https://www.admin.ch/gov/fr/accueil/documentation/communiques.msg-id-83135.html)

In Germany (Gailing & Moss, 2016; Bourgeois, 2011; Gamberini, 2016), solar and wind energy have been more developed, and the German areas of the Upper Rhine often stand as models for cross-border French and Swiss territories (Burger & Weinmann, 2013; Lestrade & Salles, 2019). The most frequently mentioned variable is the price of electricity, which is higher in Germany than in France, and might be the reason for the promotion of the more profitable solar energy.

In Germany, solar energy owes much of its development to citizen initiatives. The favourable regulatory context, due to the decentralisation and liberalisation of the energy market in the 1990s, led to the multiplication of such initiatives. Citizen protest movements against nuclear power, which have been active from the start in Germany (especially in the Upper Rhine (Pohl, 2016) and have gained momentum in the aftermath of the 2011 Fukushima nuclear disaster, have reinforced efforts to put in place alternative energy sources (Gamberini, 2016) and the creation of numerous citizen energy cooperatives at the municipal and intermunicipal level. Yet, this important development of citizen energy cooperatives on the German side of the Upper Rhine seems to have slowed down over the past few years, after new regulatory measures were introduced making renewable energy production less profitable (Hamman & Mangold, 2020; Lestrade & Salles, 2019).

In France, as in Switzerland, citizen energy cooperatives are now developing and organising into regional networks (Christen & Hamman, 2015b; Hamman, 2022a), with the creation of the Grand Est Citoyen et Local d'Énergies Renouvelables (GECLER) network in 2019 on the French side, and the development of a Swiss Association for citizen energy (ASEC) in French-speaking Switzerland since 2018. The role of citizen energy for the future of an integrated renewable energy market in the Upper Rhine therefore deserves attention. However, the administrative hurdles encountered by energy cooperatives in France are placing them at a disadvantage compared to the large power grid companies.

While the development of renewable energy largely depends on the commitment of local actors, the national context conditions, and the launch of new projects. National governments, federal states (i.e., the German *Länder*) and the Swiss cantons provide the main incentives in the form of new regulations or financial tools such as feed-in tariffs. Local actors are generally well aware of these regulatory contexts, whereas they are generally unfamiliar with European policies and norms. The focus of local administrations on energy issues is further translated into dedicated services and agents (e.g., *Klimaschutz manager* in Germany or *chargé de mission transition énergétique* in France).

Importantly, regulations and financial tools can both support and hinder the development of renewable energy (Burger & Weinmann, 2013; Campos *et al.*, 2020). For example, the decrease of electricity feed-in tariffs does not facilitate the development of small photovoltaic installations, whereas they are favoured by citizen energy cooperatives or rural communes desirous of "spinning off" small-scale renewable projects across their territory. This testifies to the importance of the national and regional legislative and institutional context, which can lead local players to draw different conclusions depending on their country.

In terms of cross-border cooperation on renewable energy projects, the WP4 survey revealed only a small number of cases. Existing cooperation and exchanges have primarily been initiated by German and French actors, who value the opportunities for sharing and learning from each others' experiences. However, these initiatives have not resulted in concrete common projects.

Concerning regulatory issues, the development of renewable energy is hampered by numerous legal constraints, both due to the national regulatory context and to the need for translation between different regulatory contexts when cross-border cooperation projects are undertaken (for instance for prosumers: (Campos et al., 2020)). Therefore, there is a need to revise the norms for urban planning documents – i.e. concerning the implantation of renewable energy installations in specific areas with specific conditions – and the feed-in tariffs, which are very different depending on the country.

This leads us to economic issues. To organise an integrated market in the Upper Rhine, renewable energy production needs to gain a competitive advantage over nuclear or fossil fuel-based energy production. Incentives, such as new regulatory tools and financial support, should be able to increase their competitive edge and limit the role of big non-renewable energy producers. That is why local authorities who are promoting new projects are asking for the means to hire new employees familiar with the issues raised by the Plan Climat and the future of the areas' energy systems.

As far as technical issues are concerned, the development of renewable energy systems is still being carried out within the framework of the dominant socio-technical systems (Christen & Hamman, 2015a; Labussière & Nadaï, 2018). Debates may thus arise as to the ecological impact of some of the technical innovations designed to increase the share of renewable energies. The use of geothermal energy, for instance, can be questioned, given its limitations and impacts on the ground, especially in the Upper Rhine area where numerous seismic tremors have brought geothermal drilling projects in the Basel region to a halt.[7]

Finally, the socio-political points developed in this working paper should invite political authorities to take the various actors involved in the production and consumption of renewable energy into consideration (Hamman, 2019), and, in particular, to avoid granting only exemplary status to citizen projects. Such initiatives, which are dependent on strong political and financial support, aim to relocate energy issues and give a role to citizens in an energy system that is all-too-often dominated by national industrial companies and works in dematerialised ways

[7] This happened in 2006 but also in 2013, despite the use of another technique. In Alsace too, the recent seismic tremors which occurred in Strasbourg in 2019-2020 and were attributed to geothermal drilling have reopened the debate about the safeness of this renewable energy source. Sources: https://www.rts.ch/info/regions/autres-cantons/5080077-forage-geothermique-suspendu-a-stgall-apres-un-seisme.html; https://www.lepoint.fr/societe/alsace-un-projet-de-geothermie-profonde-a-l-origine-de-seismes-26-11-2019-2349537_23.php; https://www.dna.fr/environnement/2020/10/28/les-seismes-de-la-nuit-dernieres-lies-au-site-de-geothermie

limiting the appropriation of energy issues by inhabitants and consumers. Better awareness of the relationships between producers and consumers would contribute to a better, more concrete apprehension of current and future challenges.

The price of energy, nevertheless, remains a central factor, as argued by certain community project leaders who are demanding a rise in the price of nuclear or fossil fuel-based electricity to make renewable energy more competitive. One of the main issues is to avoid creating new socio-economic divides on the (selective) grounds of ecology, as was the case following the closure of nuclear power plants in Germany (Bourgeois, 2011) or during the "Yellow Vests" movement in France.[8] So energy justice is a major issue (Day, 2021).

One of the possible uses of this study is to suggest outlines for future policies. As such, we have shown that the development of renewable energy associated with the repertoire of energy and ecological transition – which is taking a growing place on international and national agendas worldwide – involves multi-scalar challenges that combine regulatory, economic, socio-technical and socio-political dimensions, including community energy (Bauwens et al., 2016).

In regulatory terms, it could be a matter of bringing frameworks closer together at international (here in the EU) or interregional level, whether it be planning documents for setting up a renewable energy installation, texts governing renewables production or setting feed-in tariffs (Cointe, 2016).

Economic issues include both the role of incentive policies (electricity prices which vary significantly from one country to another and often do not take into account the ecological costs of production; ad hoc financial support for renewables, etc.) and issues of scale, because renewable energy projects may involve stakeholders of different sizes, and also because energy efficiency and economic profitability are not the same depending on the scope of the projects (economies of scale and operating costs on the one side, versus storage and distribution network issues on the other side).

At a socio-technical level, one permanent issue is the need to take into account the divergent viewpoints around concrete equipment, once the move is made from consensual principles about energy transition to operational devices such as smart metres or storage solutions. The same goes when the increase in renewables, commonly seen as "virtuous alternatives" to carbon energies, is weighed against the ecological impact of these technical innovations (i.e. growing debates on "rare earths", etc.). This socio-technical perspective leads to the identification of several interconnected issues: the question of the structuring of economic sectors (both their territorial dimension and their large-scale interconnections); that of the foundations of the energy transition on which to agree from a societal point of view ("better or less", in other words should the transition to renewables be linked with greater energy sobriety?); and that of the energy mix between renewables, bearing in mind that the social acceptability (Depraz et al., 2015; Roßmeier et al., 2018; Ravignan, 2021; Schumacher et al., 2019) of energy technologies and infrastructures differs significantly from one source to another, for instance between deep geothermal, wind and photovoltaic energy. Finally, our study of the interplay of actors at the URR level has more broadly shown the role of

[8] The Yellow Jacket movement (*Gilets Jaunes* – after the visibility waistcoats worn during demonstrations) appeared in France in October 1918 to protest against the rise of the price of motor fuels resulting from the increase of the domestic consumption tax on energy products (TICPE). Their demands then extended to other social and political issues and led the State to launch a national debate: Bourmeau Sylvain (ed.), 2019, *« Gilets jaunes »: hypothèses sur un mouvement*, Paris, La Découverte.

intermediate actors, in particular those with expertise in supporting projects: climate and energy project officers in local authorities, national networks of citizen cooperatives, etc.

At the socio-political level, one major challenge consists in recognising the role of all the actors involved in one way or another, from production to consumption – whether they are institutional actors or newcomers, inhabitants or activists, etc. (Cao, 2015) – in order to make energy circuits more visible. This may involve a certain re-appropriation of energy issues locally (not synonymous with autarky for all that), to which renewables can contribute. The price of energy and electricity is also a political lever to make renewables more "competitive".

Finally, renewable energy transition in the URR appears as a multi-scalar issue, under a double aspect (Hamman, 2022a, 2022b). On the one hand, the question of the relationship between general interest and territorial interest appears when considering the levels at which decision-making processes need to occur and the processes of legitimation: general interest is not necessarily defined as global or national, and territorial interest is not only local. This also manifests a tension between territorial energy autonomy and solidarity between territories or even interconnections on a larger scale, knowing that renewables are intermittent energies. The importance of community benefits – whether it be community ownership, development for different local actors in the sector, etc. – should not be overlooked either in enabling citizens in the energy transition (Pellegrini-Masini, 2020: 209–210). On the other hand, the governance of energy transition implies a form of individual responsibility, or even of "governmentalization" of change – in Foucault (1991)'s sense, i.e. the production of individual self-regulations –, which can render invisible the weight and role of institutions and social structures in reality, if the transition is to be as fair as possible. As Benito Cao writes, "governmentality represents a shift from the rule of law (a set of codes that is explicit and visible) to the rule of conduct (a set of codes that are implicit and shape will formation). […] Political authorities still exist, but govern in a different way, *through* citizens rather than *over* citizens, shaping human conduct through the formation of will, ultimately inducing self-government" (Cao, 2015: 148). The increasing calls on consumers and households to achieve energy sobriety are an example of sustainability governmentality and reveal a redefinition of the scales of public action (Hamman, 2019: 30–38), from collective scales (concerning in particular social access to goods and services, and unequal distribution linked to the unequal economic capital of social groups) to an individual scale, for example concerning domestic energy consumption. This process of rescaling results in concealing the differing capacities of individuals to engage into action, which depends, for example, on whether they are social housing tenants or homeowners. In this respect, new energy developments dealing with community and renewable energy continue to raise concrete socio-environmental – both distributional and procedural – justice and equity issues (Day, 2021) that deserve attention.

Energy transition policies are today faced with the challenge of changing current perceptions of the costs and benefits of "alternative" energy choices (Pellegrini-Masini, 2020: 215) in order to convince economic actors, local decision makers as well as citizens and inhabitants, in both urban and rural areas. Regional energy markets, such as that of the Upper Rhine in Europe, make it possible to better understand this by coupling cross-border realities with long-term national energy trajectories and supranational objectives at the European Union level (Bafoil, 2016). Local innovations and social change do not simply become reality through the national and international diffusion of exemplary "models", even that of the famous German *Energiewende*. As concrete practices beyond more general discourses, energy transition appears fully embedded in a law-economy-society triad, that corresponds to social transactions as well as to temporal and spatial contexts always evolving and interacting on several political, societal and human-nature levels (Baggioni et al., 2019).

Chapter 6. Work Package 5: Analysis of the Regulatory Framework for the Design of the Electricity Market and Proposals for an Improvement of the Legal Framework of the Electricity Market

This chapter provides an overview of the legal obstacles and levers and possible solutions for reducing border obstacles to cooperation to develop and scale up renewable energy (RE) and make best use of potential cross-border complementarities. Based on the assumption that regulation can be either a lever or a major brake to the development of RE, the work package 5 (WP5) conducted an in-depth analysis of the impact of different European and national legal regimes promoting RE in France, Germany and Switzerland, with a particular focus on cross-border effects. Methodologically WP5 adopted both a traditional approach (legal documentary research and comparative analysis) and an empirical inductive approach based on analysis on the basis of stakeholder interviews (Aras, 2021a).

6.1 Challenges of Cross-Border Cooperation in RE Development

6.1.1 The Importance of Geographical Location of Renewable Energy Projects

As it became apparent from the research work conducted by WP2, PV has the greatest potential in the tri-national Upper Rhine region, especially for installations on buildings because of the numerous conflicts of land use, whether in relation to agriculture or nature conservation present inFrance, Germany and Switzerland.

In contrast, hydropower has no further regional development potential, except for small-scale hydropower. It should be noted, however, that hydropower is an efficient and secure way of meeting electricity demand both in France and Switzerland.

Wind energy is experiencing development difficulties in the region due to legal-administrative considerations (distance from housing), environmental considerations (presence of biodiversity and landscape protection issues) and technical considerations (military radar, meteorological radar, weak winds) but also low societal acceptance in all parts of the region. Local acceptability of wind farms is the most difficult to achieve for project developers, especially due to the "not in my backyard" syndrome. In particular, in Germany, wind energy has grown significantly over the last decade, but its development is currently at risk of being slowed down due to less advantageous financing mechanisms.

Geothermal electricity generation is heterogeneous in the study area. There is a slight difference in the development policy of this renewable energy between France on the one hand and Germany and Switzerland on the other. The first power plant in the world using Enhanced Geothermal Systems (EGS) technology was developed in Alsace and is currently in operation (Soultz-sous-forêt power plant) and a simplification of the regulations can be observed, making it easier for the project developer to obtain authorisation to explore. However, the recent earthquakes in Strasbourg in 2020 and 2021 have led the prefect of the Bas-Rhin to suspend three deep geothermal projects around Strasbourg. In Germany and Switzerland, many studies are currently being carried out and many projects are underway, but there is a reluctance to use this little-known technology: these two countries take more account of the overall risk that drilling for electricity production may entail. A common point between these three countries in their policy is the financial support given to the sector, which is considered to be the essential renewable energy for the energy transition.

Bioenergy based on biomass is one of the most widely used renewable energy sources in the trinational Upper Rhine region. By 2030, it is expected to account for 50% of European renewable energy production. Given the hazardous nature and risks of biomass installations (combustion, waste management, methanisation), the regulations governing the sector are important and service providers will need to obtain permits that comply with several special and general requirements. However, although biomass is promising, it is not widely accepted by local populations because of the direct and indirect impact it can have on the environment (deforestation), the GHG emissions for which it is responsible and the conflicts in land use (nature conservation vs agriculture) and raw material uses (food vs fuel) that it can trigger. In all three countries, the sector would benefit from more precise regulations that would allow biomass to be managed in a more sustainable way.

Our empirical results show that all three national regulatory regimes, especially as regards environmental law, are inadequate for cross-border projects. Impact studies, public enquiries and access to justice are all tools that are not currently designed to meet the challenges of cross-border projects and therefore do not facilitate the social acceptability of cross-border energy projects, e.g. citizen energy cooperatives.

6.1.2 The Key Role of (Financial) Support Mechanisms

As regards photovoltaic energy, the limitation of the feed-in tariff and the remuneration supplement, notably in France, open up a 'direct contracting' opportunity for the production of less than 100 kWh (recently modified from 100 to 500 kWh by the Order of 6 October 2021)[9]. The complexity and length of the administrative procedures are also among the obstacles which slow down the development of the sector. For small projects (<100 kWh), another issue is related to obtaining bank loans which is often difficult.

Tendering procedures also limit public participation in support mechanisms due to the highly competitive environment. In particular, wind energy has grown significantly over the past decade but its development is currently at risk of being slowed down due to less advantageous financing mechanisms. For instance, in Germany these conditions became less advantageous with the introduction of calls for tender in 2017 and the end of the first wind feed-in tariffs at the end of 2020. In France, there is also the problem of profitability concerning collective self-consumption, for which there is not enough support and incentives for its development (no feed-in tariff or tax exemption).(Aras et al., 2021)

6.1.3 The Complexity and Length of Administrative Procedures

In general, the difficulty level of administrative procedures hinders the development of sectors. This administrative obstacle is partly the cause of the discrepancy between the national objectives programmed for different timeframes (2023, 2028, 2030, etc.) and the reality of RES development on the ground. The existence of several layers of administrative formalities (“administrative millefeuille”), the evaluation of projects on a case-by-case basis due to their technical character and geographical location, or the delay in certain regional plans for the development of RES, make the concretisation of renewable energy projects complex in terms of time. For example, biomass is one of the most used RES in the trinational Upper Rhine region. However, given the hazardous nature of biomass activities (combustion, waste management, methanisation), the regulations governing the sector are strict and service providers must obtain permits that comply with several special and general requirements. Similarly, with regard to onshore wind power, the issue of social acceptability makes the legal framework for the development of these technologies more complex (ICPE regime - classified installation for environmental protection, applicable to most wind farms in France) which lengthens the time required to build and start using the installations. In France, onshore wind

[9] Arrêté du 6 octobre 2021 fixant les conditions d'achat de l'électricité produite par les installations implantées sur bâtiment, hangar ou ombrière utilisant l'énergie solaire photovoltaïque, d'une puissance crête installée inférieure ou égale à 500 kilowatts telles que visées au 3° de l'article D. 314-15 du code de l'énergie et situées en métropole continentale, JORF n°0235 du 8 e 2021.octobr

capacity in June 2020 was 17 GW. By 2028, this capacity is planned to double (24.1 GW until 2023 and between 33.2 and 34.7 GW until 2028).

6.1.4 European Governance on Energy Mix Challenged by National Prerogatives

The EU's competence in the field of energy is reflected in the governance of the coordination of Member States' climate (Art. 191-193 TFEU) and energy (Art. 194 TFEU) policies. This European governance is above all necessary to reconcile the supposedly contradictory challenges in the context of the massive development and upscaling of renewable energies, namely the reduction of greenhouse gases and the security of energy supply at lower cost. However, European energy governance remains limited in the face of Member States' prerogatives over their energy mix and their capacity to produce renewable energy. At EU level, there are no legal obligations to invest in specific volumes of specific technologies. Member States are also free to set their own levels of security of energy supply.

6.1.5 Lack of Legal Provisions for Cross-Border Cooperation in National Frameworks, Despite the European Strategy for Interstate Cooperation

In the Renewable Energy Directive (2009/28/EC), the European Commission provided for optional cooperation mechanisms in the framework of the European internal energy market, such as statistical transfers, the possibility of co-financing renewable energy projects, and joint support programmes, in order to achieve climate and energy targets in a timely and cost-effective manner (Articles 6-11). In the Commission's progress report on the renewable energy sector ("Cross-border collaboration and use of cooperation mechanisms")[10], it is noted that these mechanisms are not effectively used (there are currently four agreements allowing the use of statistical transfers: two agreements were concluded in 2017, one between Luxembourg and Lithuania[11] and the other between Luxembourg and Estonia[12], and two additional agreements have so far been signed in 2020, one between the Netherlands and Denmark[13] and the other between Malta and Estonia)[14]. In particular, France has not included any cooperation between 2009-2020 in its National Renewable Energy Action Plan.

However, in a spirit of solidarity and efficiency, the EU continues to encourage Member States to promote cross-border cooperation in the renewable energy sector. The European strategy on the Energy Union (COM/2015/80 final) clearly favours cross-border cooperation in the development of clean and renewable energy sources. Thus, in the latest legislative package "Clean Energy for All Europeans"[15], we find new measures in this area: the possibility of opening up support schemes to cross-border participation; the possibility of establishing Renewable Energy Communities (RECs) and Citizen Energy Communities (CECs) to cross-border participation, provided by Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources, the Renewable Energy Directive and Electricity Directive (EU) 2019/944 concerning common rules for an electricity internal market.

---

[10] COM(2020)952 final, Renewable Energy Progress Report, 14.10.2020.

[11] https://ec.europa.eu/info/news/agreement-statistical-transfers-renewable-energy-amounts-between-lithuania-and-luxembourg-2017-oct-26_en (29 June 2020).

[12] https://ec.europa.eu/info/news/second-agreement-statistical-transfers-renewable-energy-amounts-between-estonia-and-luxembourg-2017-nov-13_en (5 September 2020).

[13] The agreement is available online: https://www.euractiv.com/wp-content/uploads/sites/2/2020/06/Agreement_for_Statistical_Transfer_of_Energy_from_renewable_sources.pdf (29 January 2021).

[14] The agreement is available here: https://www.riigiteataja.ee/aktilisa/2090/9202/0001/Malta_Engl.pdf (29 January 2021).

[15] All references are accessible from this webpage: https://energy.ec.europa.eu/topics/energy-strategy/clean-energy-all-europeans-package_en (5 January 2021).

The Renewable Energy Directive encourages Member States to (progressively) open their RES support schemes to cross-border participation (cons. 2 and 23). Thus, Member States may support renewable energy projects located in other Member States. The formulation of the policies for gradual opening is left to Member States under the condition that it does not disproportionately affect national support schemes (in particular in compliance with Articles 30, 34 and 110 TFEU). In order to ensure that the opening of support schemes is reciprocal and mutually beneficial, cooperation agreements need to be signed in accordance with the principle of reciprocity between the participating Member States (recital 24). However, it has been found that cross-border cooperation is currently not sufficiently developed within national frameworks. These new schemes are not yet widely tested. Most of the support programmes implemented are limited to national renewable energy projects. For instance, in Germany there is a (partial) opening of 5% of the annual newly installed renewable energy capacity to installations in other Member States (Section 88a - Cross-border tenders - Federal Renewable Energy Act (EEG)). Only two Member States have opened up their support programme to cross-border projects: a cross-border tender was launched for the first time between Germany and Denmark in November 2016 for a volume of 50 MW of ground-mounted photovoltaic installations[16].

It has also been observed that the possibility of cross-border participation in renewable energy communities has not yet been transposed into national law. The French law on Energy and Climate of 2019 has introduced RECs but without transposing the cross-border aspect. In the trinational territory of the Upper Rhine, there is very little cross-border "cooperation" in the field of renewable energy apart from “Zusamme Solar Colmar” implemented by the FESA Energie Geno - Énergie Partagée Alsace partnership on PV, or the CERGA-RKI historical cooperation in hydroelectricity. (Hamman (Ed.), 2022)

6.1.6 The Top-Down Logic of European and National Institutions

Finally, there is a problem of discrepancy between "the facts" and "the law", making regulators’/lawyers’ work complex and not very effective. Although the renewable energy sector is promoted, the influence of local actors such as local authorities and governments, cooperatives, small businesses, citizens remains weak (epiphenomenon) within the energy market which has its own dynamics. Regulation is adapted to monopolistic players, while renewable energies mobilise small players (e.g. the cost of the grid connection tariff - tariff equalisation). Similarly, it should be noted that the decentralisation of energy could make the financing of public networks more problematic.

In addition, the phenomenon of "path dependency", especially concerning the major national energy choices (e.g. nuclear in France, coal in Germany), is not sufficiently addressed. Consequently, despite the encouragement of communities and citizens' participation in the implementation of the energy and decentralised transition, the top-down logic of European and national institutions predominates. This still raises the question of energy justice in the impact distribution of the energy transition on the territories. (Aras, 2021b & Aras, 2021c)

6.2 Recommendations to Improve the Regulatory Framework

Special attention is given to the hydrogen sector in the tri-national Upper Rhine region. More generally, hydrogen is strongly supported in Europe, with the year 2020 being marked by the adoption of national and EU hydrogen strategies: Germany in June 2020, France in September 2020, European Commission in July 2020. This was associated with numerous investment pledges (see comparative brochure). Green, renewable hydrogen has many interesting

[16] https://planetsave.com/2016/10/13/germany-denmark-launch-cross-border-solar-electricity-auction/ (29 June 2022).

properties: apart from potentially enabling efficient energy storage, it can become an effective alternative to conventional fuels, could be used in the chemical industry or as an efficient source of electricity and heat. However, hydrogen is not currently renewable. In order to achieve the ambitious national and European development targets, major technical and regulatory advances are still needed. Differences between regions as well as the lack of regulations and transport infrastructure are still holding back the development of the sector. There is also a problem of harmonisation of legislation on a European scale with regard to the different existing definitions.

Although the three countries recognise the potential of hydrogen-based technologies for the energy sector, their development strategies differ. In Switzerland, the Federal Council recommended in 2021 a strategic orientation for the future role of hydrogen through the motion "Green Hydrogen Strategy for Switzerland" and the postulate "Hydrogen - Analysis and Options for Action for Switzerland". Among other things, it is being examined where the use of hydrogen makes sense, where it is produced, how it is transported, imported and possibly stored, and what regulatory framework conditions are necessary for the development of a hydrogen market in Switzerland. France, on the other hand, is already seeking to develop its national hydrogen sector and is encouraging its hydrogen producers. Germany, finally, is planning to import green hydrogen and is focusing on research and development, seeking to export its technologies and manpower.

6.2.1 Reinforcement of Cross-Border Dimension

The EU intervention in the policy field of energy in relation to the establishment of the internal energy market consists of organising its general framework in such a way that policies are taken in accordance with common objectives and in a spirit of solidarity between Member States, in order to ensure, in particular, the continuity of energy supply. The European Commission, in its Impact Assessment for the 2030 Climate and Energy Policy Framework (COM (2014) 15, SWD (2014) 016), makes it clear that Member States are increasingly interdependent on the requirement to provide secure, sustainable and competitive access to energy, especially as energy transition will be less costly if Member States cooperate. However, cross-border cooperation in the development of RES ("cooperation at production level") at local level, within a defined territory, highlighting the interaction of local actors including local authorities, energy cooperatives/communities, companies and network actors (such as local electricity utilities), is a research area that is still little known due to its recent emergence. Cross-border energy cooperation within the EU is first observed through the transmission network and the concept of interconnection, on a much larger scale ("grid level cooperation"). At the territorial level, cross-border cooperation is not a sufficiently developed approach in national regulations. At present, the only way to participate in renewable energy installation projects planned in the territory of a Member State is through equity financing.

The cost of renewable energy integration into the grid also plays an important role. The geographical location of renewable energy installations is important, as the development of new energy sources may require grid reinforcement or construction of works. The issue of cost is seen as a constraining factor for decentralised renewable electricity generation. It is therefore necessary to achieve an optimal integration of renewable energies in each geographical area to find the best compromise between grid and production. More generally, this compromise would ensure energy justice in the distribution of the impact of the energy transition on the territory.

Our research shows that there is a need for a favourable regulatory framework to strengthen energy decentralisation in cross-border areas. The multiplication of local renewable energy initiatives could not be envisaged without a favourable financial and legal framework. In this respect, academic work has already shown that there is a wide range of interconnected factors causing functional uncertainties in the decentralised electricity production from RES. Among these functional uncertainties is mainly the behaviour of consumers and their adaptation to the emergence of innovative technologies (such as smart grids). Thus, the role of local actors is crucial in the implementation of the energy transition at regional level. In the cross-border context, it is also noted that in the absence of executive powers for institutional actors, cooperation serves to reinforce traditional intergovernmental relations rather than to consolidate the functioning of a multi-scale system. Thus, it is very important to provide all actors with an "enabling framework" to strengthen decentralised renewable energy development at both local and cross-border levels. This certainly requires the intervention of national and/or regional governments, depending on the political system and energy policy of the country, but does not prevent the introduction of specific, even experimental regulations. In this sense, the cross-border territory can be considered as a pilot territory for implementing regulatory and legal-administrative experiments to achieve European and national objectives for scaling up renewable energy. The idea of an experimental laboratory is all the more feasible as the current legal framework resulting from the Clean Energy Package is favourable to experimentation in the field of renewable energy development.

Public health and environmental aspects also need to be taken into account, as all renewable energies have impacts on the environment and human health. The construction of solar panels requires rare metals which are not all recyclable. In addition, if the panels get too hot, birds and insects can get burnt or even die if they fly over the cells. Hydroelectric plants have an impact on the surrounding area: to build the reservoir, land is being flooded. This results in the destruction of forests, natural habitats, farms, landscapes, and sometimes communities may even be relocated. Wind turbines have an impact on human health: the stroboscopic effect produced by the shadow of the blades sometimes leads to epilepsy, nausea or malaise. Psychological factors (individual sensitivities, social and financial factors) associated with the presence of wind turbines and their nuisance (noise, landscape, etc.) can create discomfort to people living near wind turbines. Biodiversity is often impacted (especially birds and bats). In addition, some fifteen rare metals and copper are also present in wind turbines and are difficult to recycle. As for geothermal energy, it causes hydrological risks: the surrounding water can be contaminated by sulphide, salt and other molecules. The operation of a geothermal station can also lead to pollution of the surrounding air due to the substances produced by geothermal energy (hydrogen sulphide, carbon dioxide, ammonia, methane, buron). Once in the atmosphere, they can lead to acid rain or disease. Finally, mining involves geological and seismic risks. Landslides can be felt near geothermal installations. Biomass is also a source of nuisance. The environmental impacts can be divided into three categories: deforestation; harmful emissions (including carbon monoxide and nitrogen oxide); and changes in the surrounding habitat. Finally, hydrogen is a dangerous product. This dangerousness is socially difficult to accept. Although the risks of explosion and accidents are few, they can be devastating. These various disadvantages of renewable energy in terms of health and the environment may be further accentuated in a cross-border context, as law, particularly environmental law, is inadequate to assess the impacts of cross-border projects.

The work package 5 (WP5) has prepared a brochure providing a synthetic overview of the regulations relating to wind, photovoltaic, geothermal, hydropower, biomass and hydrogen in the Upper Rhine region, highlighting the different regulatory aspects in the development of renewable energy, including the cross-border aspect. (Aras, 2021) Given that the European legal framework favours cross-border cooperation in the context of the energy transition and that national laws thus adapt to the requirements of implementing the energy transition on their territory through the development of renewable energy technologies, the decentralisation of the production and consumption of electricity from renewable sources is a key aspect in the trinational region. Nevertheless, the requirements of maintaining security of supply and the coexistence of various issues (economic, environmental, social, etc.) accentuate the need for a much more centralised legal-political framework.

Chapter 7. Work Package 6: Study of Incentive Structures in Energy Supply

7.1 Energy policy potentials and the role of energy cooperatives and political decision-makers

Within the framework of Work Package 6 (WP6), it becomes clear that the integration of the European energy market is the central element for achieving a European Energy Union. This strives for a climate-neutral, low-emission, secure and cost-effective energy supply through renewable energies in Europe. The possibility of using the transmission capacities between the individual EU member states for cross-border electricity trading, as well as the expansion of market coupling, are prerequisites for this. For historical reasons, the cross-border interconnection points between the individual member states are rather weakly developed, as the exchange with neighbouring states has played a subordinate role up until now. With the change in energy supply and an increasing demand for electricity, the grids must be expanded across borders. However, various barriers stand in the way of grid development projects that are needed for the current and immediately planned generation capacity of renewable energies. A core problem is national energy policy preferences as well as public acceptance of new energy projects within the different regions of the EU. Long and different administrative processes within and between EU member states result in delays in grid expansion of up to 20 years. The Energy Union's governance system includes few liabilities and no sanctions. Thus, it is up to the member states at the national level to integrate the targets, strategies and measures for the climate goals into their national climate plans. In the event of delays or non-compliance, there are no sanctions, thus limiting the scope for action to combat climate change in terms of energy policy. The cost of developing the grid requires a strong and coordinated policy, technical and financial effort that will take the whole of Europe decades. But the costs of expansion are far less than the long-term economic, environmental and security of supply costs that the EU would face without these measures.

In the development of the energy transition so far, the multitude of small-scale energy generation initiatives has been a key factor in its success. In particular, the rise of new, decentrally organised actors in the provision of renewable energy remarkably support the “Energiewende”. Intensifying cooperation and continuously activating private capital is essential for continued success. In the further course, the role of cooperatives in the realisation of the goals will be shown. It also points out the problems that arise in this context.

Politicians and scientists agree that the bottom-up movement within the energy transition is highly relevant and also has an influence on citizen engagement (Ohlhorst, 2018a). The core competence of cooperatives is the accumulation of financial resources and interests, the pursuit of common goals and the intensification of communication. As a result, they have the potential to increase acceptance of renewable energy and promote its expansion. Within the framework of the counselling and further education offered, everyday lifestyles, but also long-term aspects, are brought closer to the citizen. In this way, society is made aware of the need to reduce energy demand and increase energy efficiency. Participation in educational activities increases the awareness of citizens, which is reflected in intensified participation in energy policy. Furthermore, it is possible to reach previously unmotivated, as well as undecided, citizens and encourage them to show commitment. Due to the local anchoring and the non-profit orientation, it is easier for the organisation to build social capital and trust in the long term. This is especially reflected in the transparent investments and regional value chains. Through their local ties, the cooperatives are aware of the special features and strengths of the catchment area and know how to make the best use of them. Accordingly, they support an increase in local added value and economic growth. Under the principle “from the region for the region”-contracts, e.g. for the construction of facilities, their maintenance and operation, are awarded to local companies and new jobs are created in the immediate vicinity. In addition, the municipalities generate rental and tax income through cooperative activities. Due to the equal and fair membership fees, it is thus also possible for financially weak households to participate in the energy transition. Conversely, the cooperative also contributes to a reduction in energy poverty. Aspects of gender neutrality are also taken into account in the non-discriminatory selection of potential members. Compared to other forms of organisation, instruments such as gender budgeting, women's quotas and leadership training are easier to establish (Eichermüller et al., 2017). Due to the underlying diversity, cooperatives have the potential to fully take into account the needs of their members and to fully exploit their know-how. Since the activities of a cooperative are geared to the needs and objectives of its members, it can act more flexibly and adapt to local conditions. What appears to be advantageous in the first instance can quickly turn into an obstacle. Diversity is characterised by the socio-economic composition of the members and the available budgets. If interests differ greatly, it is almost impossible to make uniform recommendations for action (Schröder & Walk, 2014).

In particular, the field of renewable energies is characterised by a dependence on local conditions, weather influences and social acceptance. The Upper Rhine region has different languages and cultures due to its transnationality, which can be an obstacle to cooperation. In addition, Germany, France and Switzerland are in different starting positions with regard to objectives, electricity generation and legal framework conditions. For cooperatives, however, the circumstances offer the opportunity to play an essential key role. Given their characteristics, they can flexibly adapt to the geographical and legal differences. Building a sense of community in the region is a promising basis for further cooperation. Cooperatives could set an example to other companies with small, specially organised projects. Other actors (public authorities or conventional companies) could follow their example and intensify investments in transnational cooperation.

Potential obstacles and weaknesses of the cooperative model should not be ignored. For the Upper Rhine region, the problem of the loss of regional reference should be emphasised above all. Cooperation in the Upper Rhine region is not only supra-regional, but goes beyond national borders as well. In addition, the countries have a different understanding of cooperatives. This can make the search for potential cooperation partners more difficult and may turn out to be incorrect in retrospect. As already described, the membership of a cooperative is characterised by voluntariness. As soon as members feel that their interests are not adequately represented, there is a risk that they will turn away from the cooperative. For this reason, conflict management is needed to ensure that members are in favour of the cooperative's activities. Countries belonging to the focus region have different cultures, languages and attitudes. Neglecting these aspects can lead to misunderstandings, resulting in inefficient cooperation. In addition, language barriers impair the coordination of activities, which in turn makes cooperation more difficult (Braun et al., 2019).

Furthermore, the dependence on the legal framework is one of the biggest obstacles for cooperatives. In the context of this research work, the amendment of the Renewable Energy Sources Act (EEG) was analysed in more concrete terms, as it optimally describes the problems at hand. Even recently, when the EEG was introduced, Germany recorded significant movements and took on an international pioneering role in climate and energy policy. This success was also reflected in the number of energy cooperatives founded, which experienced a real boom in the following period. Until the aforementioned amendment of the EEG, the support mechanism was a fixed feed-in tariff, the amount of which was determined by parliament depending on the technology and forecast. However, from the point of view of the political decision-makers, this was problematic because the actual costs differed from the forecasts. Subsequently the subsidy level turned out to be too high or too low. The solution that resulted was the tendering procedure that is still in place. However, there is now a danger that this changeover will increase the chances of the large, financially strong and supra-regionally active providers to increase their market shares, while the changeover will be much more challenging for smaller projects with a local character. This is because up until this point, the feed-in tariff and subsidised direct marketing allowed the players to calculate the investment risks and better evaluate projects. It offered the actors planning security and reduced the transaction costs for the investors involved. However, the amendment poses a serious threat to cooperatives, as they do not have the necessary financial resources. Accordingly, they are not able to bear the transaction costs and risks incurred, for example, by participating in the auctions. It is to be expected that in the future the market will concentrate on large market participants and reduce competition in the electricity market. In the auction process, cooperatives face the uncertainty of winning a project. However, even if they are awarded a project, the costs may turn out to be higher than forecast. In this case, the organisation faces significant penalties. In addition, large companies, unlike cooperatives, have a broadly differentiated portfolio. This enables them to reduce uncertainties by spreading risks more widely. Accordingly, it is more difficult for affected cooperatives to cushion the costs that arise. It stands to reason that they will fail due to the risks and the complex tasks (Ohlhorst, 2018b). Financial support thus represents the most important factor for successful start-up and operation. In the context of the amendment of the Renewable Energy Sources Act, cooperatives are encouraged to diversify their portfolios more broadly or to enlarge their organisation in view of the risks. Enlargement can be achieved by increasing the number of members, membership fees or by removing the regional focus. However, when designing the financial contributions, it is important to ensure that all social groups are reached. Under this condition, local acceptance is promoted to the greatest extent possible, which in turn affirms the energy transition (Wierling et al., 2018).

Furthermore, digitalisation offers cooperatives the opportunity to overcome hurdles. Consequently, new business models can be developed that go beyond the previous areas of activity. In this respect, digitalisation offers the advantage that information is freely available to everyone, at all times. In addition to a significant reduction in information costs, work processes can also be automated and contact with stakeholders optimised. In this context, efficient education as well as stakeholder engagement at project and company level is possible (Bertram & Primova, 2019). Furthermore, the use of digitalisation removes the underlying problems of reputation and unbalanced socio-demographics. Online presences, especially in social media, offer the opportunity to intensify contact with young citizens. In addition, the internet is an optimal information platform and enables stakeholders to express non-binding feedback or wishes. With the help of an appropriate presentation of the relevant information and the demonstration of the advantages of cooperatives, new potential members can be won - a strategy that has already been used by prominent cooperatives such as RTE, TennetTSO, National Grid Uk and 50 Hertz for quite some time. Moreover, virtual educational activities offer the opportunity to reach sections of society that would otherwise not attend the seminars or workshops (Bhagwat et al., 2018).

Apart from online tools, qualified representatives of the cooperative could give lectures at universities or schools. Climate, environmental and energy issues would be used to encourage stakeholders to engage with the energy transition. The concept is so promising precisely because the young generation already shows great commitment to climate and environmental policy, but is not informed about the connection with the energy transition. In addition, cooperation with social enterprises can lead to a boost in image. As an example, the previous cooperation between Swissgrid and Greenpeace, WWF, ProNatura and other organisations is worth mentioning. Within the framework of this cooperation, grid development in Switzerland was discussed jointly and a solution was brought about that was satisfactory for all parties involved. From the perspective of the cooperative, one not only benefits from the support of the respective organisation, but the prospect of tapping into new stakeholder groups is offered (Bhagwat et al., 2018).

For a comprehensive analysis of the importance of energy cooperatives, the problem of financial hurdles is addressed. The Somenergia cooperative contradicts the assumption that an expansion of the number of members or the geographical catchment area is accompanied by considerable risks. Founded in Girona in 2010, the cooperative is not only Spain's first energy cooperative, but has also become an international role model. With its current 66,933 members, it is one of the largest cooperatives and its activities extend across the entire country (Somenergia, 2020; Kunze and Becker, 2015). However, developments in Germany also show that more and more cooperatives are breaking away from the local environment and increasingly operating regionally. This is due to the cooperation of several cooperatives or the inclusion of new stakeholders (smaller companies, local energy suppliers). As co-operatives mostly encounter obstacles in national framework conditions, cooperation with local authorities and decision-makers can prove beneficial. Through this cooperation, the cooperatives not only gain more equity capital, but also other financial support, e.g. in the form of easier access to loans and guarantees granted. In addition, they benefit from easier access to land due to the cooperation and benefit from faster processing in approval procedures. Municipalities also benefit from cooperation, which is why they show great interest in cooperation. In addition to the jobs and tax revenues created by the cooperation, the municipality can also act as a role model and pioneer for other municipalities (Meister et al., 2020).

One of the main causes of the delay in the expansion of a European internal electricity market can be traced back, within the framework of a public choice analysis, to the fact that the EU Commission and the EU Parliament also seek to maximise their influence with centrally oriented energy policy-making, which in turn runs counter to the incentive of politicians to allocate national energy rents to maximise their own benefit (Gawel et al., 2014). This goes hand in hand with the fear that an EU-wide allocation of energy production capacities could negatively affect national industrial structures (Strunz et al., 2014). Moreover, energy supply as a fundamental good is central to national competitiveness (Haas, 2019). Further difficulties of the internal market can be derived from structural differences in RE support schemes, grid infrastructure and energy mixes (Munaretto et al., 2019; Schülke, 2010). For the Trinational Metropolitan Region Oberrhein (Upper Rhine) (TMO), Munaretto et al. (2019) were able to identify different regulations, lack of information exchange, lack of political trust, diverging governance structures as well as financial and bureaucratic obstacles as the main barriers to political electricity market cooperation between France and Germany.

As the Lisbon Treaty grants member states sovereignty over their energy mix (Art.194, para.2, TFEU), the EU Commission's strategy is to influence national energy policies by removing potential barriers to the common internal market, which all member states have committed to establish (Strunz et al., 2016). Together with the "Clean Energy for All Europeans" package that obliges member states to develop national action plans that are consistent with the climate objectives of EU policies (Art. 13-15, 25, 39 RL 2018/1999/EU). In relation to the path dependencies described above, the EU assumes different roles: On the one hand, it is an external, outside force that can initiate an immediate policy change through a drastic event, e.g. in the form of a court case, or it is in the position of an independent "change agent" that actively influences the political interaction of the member states in the form of negotiations with the member states, e.g. with regard to the guidelines for state aid. Leiren and Reimer (2018) were able to observe this active role of the EU Commission in the changeover to the auction system, which from 1990 onwards gradually exerted pressure on Germany to switch to a subsidy system that was more in line with competition and, in view of an impending insolvency of the Big Four, expressed as a "shadow negotiator", in an opaque form for the Bundestag, that the exemption of electricity-intensive companies was not compatible with the state aid regulations (EC, 2013; Gawel & Strunz, 2014), which would have resulted in billions in back payments from the affected industries. However, the subsidies were considered necessary by German politicians to find an energy transition consensus, which is why they felt compelled to change the subsidy, which was simultaneously included by the EU Commission in its guidelines on environmental and energy subsidies, which are de facto binding for all member states (Leiren & Reimer, 2018). According to the researchers, the EU Commission was thus decisive, or contributed to a considerable acceleration, in paving the way for an energy policy of industrial interests. A decision that also suited German politicians in that they could shift the responsibility of the policy change to a higher level, thus escaping the many veto points of the federal system and giving the proponents of the RE faction fewer opportunities to resist, which in turn illustrates the tendency of national politicians to shift politically unpopular decisions to the higher EU level (Leipprand & Flachsland, 2018).

The feared loss of power is also reflected in the relationship with Switzerland, which has not been able to reach an agreement with the EU on an electricity market agreement since 2007, as the EU ties the conclusion to other institutional agreements, which in turn, due to the reduction of autonomy, is highly controversial among voters and politicians. The current state of mostly informal agreements, significantly weakens Switzerland's position in the European electricity market (Thaler, 2020; vanBaal & Finger, 2019), especially since the introduction of the "Clean Energy for All Europeans" package, which aims to harmonise legislation between member countries to strengthen the internal market.

One of the most important implications for fast-tracking the energy transition is the need to formulate credible, clear and time-bound policy objectives and coherent policy measures. In addition, a technology phase-out could be implemented more easily if the policy would at the same time also make it easier for conventional industry to switch to alternative technologies, while balancing decentralised interests (Kungl & Geels, 2018). In order to avoid societal and industrial resistance, it is important to first implement reform projects from which "winners" emerge when arranging them over time (Rodrik, 1996). Political messages should focus on the creation of new jobs instead of the loss of jobs, which must be implemented consistently in the regions affected by structural change through credible compensation, the establishment of new institutions and retraining or early retirement measures. The deviation from past promises to the detriment of the environment, which is linked to the problem of political haggling for votes, could be flanked with stronger legal safeguards and institutions that appropriately restrict the political discretionary scope of resource redistribution (Jacobs & Matthews, 2017; Uzar, 2020). External monitoring of compliance with climate targets, as created in France with the establishment of a new institution, the 'High Council for Climate Affairs', can also be helpful (Millot et al., 2020). According to Fesenfeld and Rinscheid (2020), using political messages that emphasise the urgency of climate change to mitigate temporal discounting only increases the approval of "low-cost" political measures, but does not enable any behavioural change or increased acceptance of drastic reform projects due to the emotional distance. Nevertheless, the identification of temporal risks in connection with political measures aimed at reducing the climate problem, taking into account the temporal restrictions of politicians, is quite reasonable. Especially the combination of different policy instruments (taxes, subsidies) lends itself (Millot et al., 2020; Nicolli & Vona, 2019). Which, when costly interventions are presented together with offsets deemed beneficial, moderate the perceived cost-benefit ratio in a direction that increases public support (Dermont, 2019; Fesenfeld et al., 2020). Social acceptance of a carbon price increases if the revenues do not merely flow to the state budget or are accompanied by reductions in other taxes, but are earmarked for specific environmental measures or returned to lower-income households in order to reduce existing political mistrust. Approval is also increased if certain current costs are redistributed to future generations (e.g. with green bonds) or the additional benefits (less noise, air pollution) of climate protection that can already be experienced in a short period of time are emphasised (Rinscheid et al., 2020).

Caferra et al. (2021) note, in the context of the difficulty of controlling taxes and subsidies, that policies should also incorporate behavioural effects. The importance of social trust can be deliberately harnessed by using policy messages to emphasise a desirable norm, in the sense that the majority of the population is already performing the desired behaviour. Another possibility is group incentive systems, which are designed in such a way that all members receive a bonus for overall compliance. People are more willing to cooperate the more benevolent they perceive state action and the less they perceive the influence of interest groups in the form of corruption, which in turn implies strengthening political trust by increasing the transparency of state actions and public administration (Caferra et al., 2020; Hübner et al., 2020; Uzar, 2020). Moreover, given the yellow waistcoat protests and rising energy poverty in Europe, the design of a successful energy transition should take into account a socially equitable distribution of the costs incurred (Mastropietro, 2019; Poupeau, 2020). The findings of Schuhmacher et al. (2019) and Cousse et al. (2020) make it clear that policymakers should not rely on the overarching national sentiment but on local attitudes and needs when planning concrete RE projects. In the short term, it is important to actively involve those who are considering active participation (Schumacher & Schultmann, 2017). In the long term, however, the political focus should be on winning over the silent (still undecided) majority of the population in order to avoid a shift to a negative attitude. In this context, it could be useful to emphasise the various benefits of RE in a way that is appropriate for the target group; conservative voters, for example, prefer the emphasis on energy independence (Cousse et al., 2020).

In order to avoid local resistance, it is important to offer a comprehensive range of information as well as visits to similar RE plants to reduce fears, or to actively involve the population in a bottom-up approach already during the planning phase. Factors that increase acceptance, such as the creation of opportunities for participation (measures with a low level of responsibility are preferred, e.g. information campaigns and consultations) or the effects of the choice of location, must be adequately considered in advance (Cuppen et al., 2020; Schuhmacher et al., 2019). Perceived costs need to be weighed, because if social and environmental costs are high, a project runs the risk of losing even the strongest supporters (Stadelmann-Steffen, 2021). The larger RE acceptance gap in the French TMO area could be improved indirectly, with an improvement of the legal framework conditions such as a priority RE grid feed-in and the reduction of bureaucratic participation hurdles. In cross-border cooperation, politicians should strengthen the joint exchange of information (Schuhmacher et al., 2019), which the work of the tri-national energy network TRION-climate in the TMO already takes into account.

7.2 Regulatory guidelines for the transformation of the European energy market

The transformation of the electricity market is being pursued by more and more countries worldwide to combat climate change. However, the political implementation in the form of the German EEG must be seen mainly as a negative example that exemplifies the consequences of turning away from Eucken's second state policy principle: failed political market governance resulted in enormous increases in the price of electricity for consumers, a low impact on climate protection and an uncoordinated expansion of RES that even challenges the stability of electricity grids in neighbouring countries (Feld et al., 2014).

The goal of promoting the quantitative expansion of renewable energies, on the other hand, was largely achieved through the high feed-in tariffs of the EEG; likewise, in terms of industrial policy, the technological development of wind power and photovoltaics could be accelerated. The complete liberalisation of the market and the associated separation of transmission system operators and electricity suppliers was in itself an optimal prerequisite for a functioning competitive market, in line with the objectives of the Freiburg School. However, the EEG legislation disregarded the second state policy principle: The state steered the investment decisions of private investors by creating the conditions for an even nationwide expansion of all energy sources: for onshore wind power plants, for example, the so-called reference yield model made it economically lucrative to expand at any location, regardless of meteorological suitability (Hilligweg, 2018). The market-based price system was therefore no longer able to develop its coordinating and efficiency-ensuring effect. This promoted a so-called produce and forget mentality among energy producers; in other words, a constant incentive for producers to increase output without considering the consequences on the market (Feld et al., 2014).

One of the positive aspects in the sense of the Freiburg School is the dissolution of the market power of energy corporations. However, the danger of market power in the electricity market has shifted to another aspect: due to the non-controllable RES feed-in, price peaks occur when strong demand for electricity meets low RES feed-in. Individual generation plants - mostly flexibly controllable coal or gas-fired power plants with high production costs - then become crucial for meeting market demand or security of supply. Their operators - mostly large corporations due to the high investment volumes - consequently receive the power to set prices within the framework of the merit order principle. At the same time, there is an incentive for price-increasing capacity restraint (Monopolies Commission, 2019). The price spikes result from the EOM crowding out those power plants which, due to the lower marginal costs of RES, are only used when RES cannot supply any or sufficient electricity. As a result, the total costs of the reserve power plants have to be covered in a very short time, or the fixed costs are distributed over a very small amount of electricity (Monopolies Commission, 2017). Due to the increasing expansion and diversification of energy sources, these power plants are needed less and less, but must still be kept available for these situations. If this is no longer profitable for the suppliers, the capacities must be tendered separately and subsidised to ensure security of supply (Buck et al, 2016).

The principle of full competition can therefore only be applied to an electricity market to a limited extent: An EOM corresponds to this principle to a large extent and more than the current market situation in the TMO with the feed-in tariffs and capacity mechanisms described. However, the evolution of markets has shown that the market failure described above can occur in the EOM. In addition to security of supply, the limitation of market power was therefore also a reason for the introduction of capacity mechanisms. However, as these are only a supplementary measure to the EOM in Germany and not a capacity market in the true sense, the market efficiency potentials that can also be tapped by a capacity market in the sense of the Freiburg School are not used (Next-Kraftwerke GmbH, n.d.). Strengthening cross-border trade can additionally reduce market power in such cases and should therefore be pursued to promote competition (Zachmann, 2013). The path dependency of the national structure of energy sources is another aspect, with the stock of conventional power plants affecting the capacity for market-based transition. The flexible hydropower plants with storage capacity are an advantage of Switzerland in this respect, in contrast to the coal or nuclear power plants in Germany or France.

However, the design of the capacity reserve tenders often keeps the inflexible old technologies in the market instead of allowing new, innovative power plant types to enter the market. The insufficient impact of the European Union Emissions Trading System (ETS) contributes significantly to the low effects of the energy transition on climate protection. Due to an excessively large number of certificates, their low price has no steering effect on emissions avoidance (Buck et al, 2016). Emissions avoided in Germany due to the high RES share in the power sector are thus shifted to other EU countries.

The research question to what extent regulatory incentive structures in the sense of New Ordoliberalism (NO) are already realised in the existing incentive structures of the EU and the TMO states can be answered with a mixed result. Neumärker (2017, p. 836 f.) presents five criteria that condition regulatory incentive structures in the NO sense. The first criterion is based on the fundamental principles of freedom from envy and conflict. The second regulatory criterion of the NO is based on the re-negotiability of rules. The third regulatory criterion within the NO is defined as the strategy-proof ordering of rules. The fourth criterion relates to the enforcement of rules. A rule framework that does not generate conflict post-constitutionally and meets the criterion of freedom from conflict, as well as being reform- and strategy-proof. The fifth criterion defines itself as the renegotiation of rules as the second best solution. Article 7 of the EU can in principle cover the rules on social acceptability of cost-benefit distribution as well as of the various national incentive instruments. The first mentioned rule shows ambiguity for criteria 1-4 and compliance for criterion 5. The second-mentioned rule shows ambiguity for criteria 1-2 and compliance for criteria 3-5. A realisation of the rule for incentive setting as well as for the different national energy policies could not necessarily be shown. Furthermore, Article 9 of the EU can also cover the rule on social acceptability of cost-benefit distribution, but criteria 1-4 are to be interpreted ambiguously while criterion 5 can be complied with. Also, the theoretically elaborated rule of different national support instruments can be traced in Article 9, but only a mixed compliance with the criteria can be seen. Accordingly, Article 9 only partially realises two of the four rules analogous to Article 7. The rules on incentive setting as well as on different national energy policies are not realised.

For the Cross-border cost allocation (CBCA) specified in Article 12 of the EU (2020), an ambiguous interpretation can be shown with respect to Rule 3 for each criterion. Meanwhile, with regard to rules 1, 2 and 4, no circumstantial evidence can be found. The Grenzüberschreitende-Erneuerbare-Energien-Verordnung (GEEV 2017) of Germany shows the violation of all criteria by the chosen interpretation based on a cooperative engagement with Switzerland and meanwhile cannot realise any of the theoretically elaborated rules. The non-consideration of Article 9 of the EU (2009) in the GEEV (2017) can only be interpreted in such a way that Germany's energy policy in relation to the EU is indeed to be considered as differentiated and thereby realises rule 2 in a negative context. The French National Renewable Energy Action Plan (NREAP)2009, meanwhile, does not show positive congruence with any of the theoretically elaborated rules and accordingly cannot comply with any of the criteria. Only in this sense can a negative relation to the rule of differentiated national energy policies be demonstrated, since the NREAP excludes harmonisation with the EU regulations. Finally, by analysing the Swiss Energy Act (2018) on the basis of Article 54, a relation to the rule of differentiated national support instruments can be shown, in which, however, only compliance with a strategy-safe order can be established.

Based on the incentive structures of the EU as well as the TMO states analysed in this work, cooperations between the TMO states are currently not planned or feasible. With regard to the EU (2009), Article 7 and Article 9 provide incentives for international cooperation between the TMO states. However, most of the criteria of the NO can only be met in this respect if the respective private stakeholders have no incentives to conceal relevant information in order not to distort the CBCA recommended by the EC (2013). Here, the EU would not only have to consider the transaction costs of achieving the necessary level of knowledge (Weber et al., 2015). The interest groups according to Resch et al. (2013) within the EU as well as the TMO states must also be sensitised in such a way that political coordination can lead the differentiated interests of the stakeholders to unified action (Pahl-Wostl, 2009). At this point, the elaborated critical approach of the NO towards conventional constitutional economics on the lack of practicability is also evident (Neumärker, 2017). From a purely normative point of view, the mentioned EU cooperation mechanisms condition cooperative EE alliances within the TMO. However, from a positive point of view, these can only be ensured under certain preconditions, which are attributed by Caldés et al. (2019) to the uncertainty regarding the costs and benefits of cooperation and are intensified in particular with the aforementioned potential information obfuscation of private stakeholders. The chosen approach of the NO to produce increased regulatory equity research (Neumärker, 2017) could be realised through the experiments noted by Neumärker. By the respective stakeholders choosing the cost-benefit allocation that is fair for them within different experiments and simulations, envy-free and strategy-safe states can thereby also be realised on the post-constitutional level.

It should also be mentioned that the EU (2009), together with the EC (2013), emphasises with Articles 7 and 9 the necessary relevance for the rule of social acceptance within the population, which is elementary for a political implementation (Resch et al., 2013). However, this circumstance is negated per se by the French NREAP (2009) and the German NREAP (2009) due to the non-consideration of the cooperation mechanisms and the corresponding Energy Act (2018) on the Swiss side.

In terms of the NO, it should be noted in terms of regulatory policy that the French "Integrated National Energy and Climate Plan for France" (2020), which will be valid from the year 2021 onwards, can remove the non-consideration of the EU cooperation mechanisms by the NREAP (2009) and thus serve as a solution approach. By enabling cooperation with partners within the Pentalateral Energy Forum based on the EU cooperation mechanisms, this could correspond to a renegotiation as a second-best solution, as the missing cooperation incentives of the French NREAP and the associated shortcomings are remedied (Neumärker 2017). From this, it is politically implicit to note that TMO cooperation could be made possible by Germany and France from 2021 onwards, but it is again questionable to what extent the French Energy and Climate Plan (2020) specifies Switzerland as a possible cooperation partner and, going further, can also comply with the NO criteria. On a politically cooperative level, the new French Energy and Climate Plan (2020) might not meet the conflict-free criterion if Switzerland's inactive observer status within the Pentalateral Energy Forum does not allow the application of Article 9 (Federal Ministry for Economic Affairs and Energy, 2020; Umpfenbach et al., 2015).

Thus, in order to concretise a TMO energy community also with Switzerland, not only the lack of a referendum within the Swiss Energy Act (2018) has to be considered. The missing application potential of the EU Article 9 (2009) analysed in this paper with third countries and thus Switzerland must also be adapted from a reform theory perspective in the new French energy and climate plan (2020). In this regard, a future electricity agreement between Switzerland and the EU (Tobler & Beglinger, 2020) could create an institutional solution concept that not only integrates Article 9 of the EU (2009), but also enables an active role for Switzerland within the Pentalateral Energy Forum in order to build a TMO energy community accordingly.

However, not only Switzerland's potential electricity agreement with the EU would have to be aligned with the criteria of the NO. On the German side, the GEEV (2017) would also have to be reformed theoretically in such a way that bilateral cooperation with Switzerland is made possible with the help of Article 9 of the EU. In addition, at the conceptual level, the GEEV (2017) would have to be reformed in such a way as to also permit projects based on geothermal energy or biomass in the sense of bilateral cooperation with France or Switzerland. While the EU (2009) allows projects based on all common types of RE, the GEEV (2017) restricts international RE projects to solar and wind plants, but geothermal and biomass plants can also be realised on the French and Swiss side (Franz et al., 2019).

By implication, this reform could comply with the criterion of freedom from conflict and also aim for projects outside of solar and wind plants. The above-mentioned reform approaches can bring about greater harmonisation of national energy policies within the TMO countries (Resch et al., 2013), which has been elaborated as an essential component of TMO energy cooperation. Should these reform approaches enable more concrete potentials to use the EU cooperation mechanisms in Directive 2009/28/EC (2009), the rules on the acceptance of cost-benefit distribution as well as differentiated national support instruments would also be complied with, as these are covered by Articles 7 and 9 of the EU (2009).

Only the rule on incentivisation is not consistently integrated in this context, neither by the existing incentive structures of the EU nor the TMO states. It is true that the EU (2018) specifies an EU-wide incentive scheme based on gross domestic product per capita in Directive 2018/842 in order to define country-specific GHG reduction targets. However, it is questionable to what extent this approach is applicable to regional incentive setting within TMO states. The analysed CBCA of the EU (2020) may also normatively condition a fair cross-border cost allocation, but it is less suitable for eliminating the public goods problem, which is characterised by the free-rider problem in international cooperations (Grasso, 2007). In this respect, Directive 2009/28/EC (2009) mentions in Article 3 separate national RES targets to be achieved in a binding manner within Mobilité Spatiale (MS) and to harmonise with the overall overarching EU target. Thereby, the different RE creation potentials and the differentiated energy mixes are taken into account in the calculation of these binding RE targets (European Union, 2009) and fulfil the freedom from conflict, as the different starting positions of the TMO states would be taken into account (Franz et al., 2019).

However, Switzerland is a third country within the EU (Swiss Confederation, 2015) and is not obliged to comply with the binding national RES targets within the EU (Consentec research consortium, 2018). In order to include Switzerland, Directive 2009/28/EC would have to be reformed accordingly and would thus implicitly violate the criteria of renegotiation certainty and rule enforcement (Neumärker, 2017). In this regard, the Swiss Confederation (2019) refers to the previously mentioned solution concept of an electricity agreement between the EU and Switzerland and sees the obligation of a binding Swiss RE target as part of the agreement. In this way, the institutional incompatibilities between the EU and Switzerland could initially be defused by means of a second-best solution and prepared as a second-best solution in accordance with the criterion of renegotiation (Neumärker, 2017).

However, binding RE targets at a strictly national level would not necessarily be equivalent to regional cooperation, as reference can sometimes be made to the German NREAP and the French NREAP (2009), which do not specify the use of EU cooperation mechanisms. Thus, it can be implicitly stated that the integration of a binding regional RE target in the sense of Gephart et al. (2015) into a rulemaking framework that is binding for the TMO states could represent a first incentive for cooperation. This would allow compliance with the rule on incentivisation, but would also need to have a clearly defined distribution of responsibilities in order to avoid the conflicts pointed out by Gephart et al. (2015) and to comply with the freedom from conflict accordingly (Neumärker, 2017). In the next step, the aforementioned harmonisation of energy policies in terms of rules could then require the use of the respective EU cooperation mechanisms to realise regional TMO cooperation. This would make RE projects feasible within the TMO states, which would also cover the rule on social acceptance as well as the differentiated national RE support instruments by using the EU cooperation mechanisms modified with the experimental simulations.

In conclusion, it can be stated that for a TMO energy market for sustainable and RE based on the NO, from a reform theory perspective, respective adjustments to the existing incentive structures would have to be made before such cooperation can be effectively established. Due to the capacity limitations of this work, limitations also inevitably arise, as the incentive structures of the EU and the TMO states analysed in this work by no means represent all relevant incentive structures that can be analysed in terms of the NO. The defined rules can also be supplemented by further rules based on the NO. An extension of the analysis would be conceivable through additional regulatory framework conditions. Within a TMO cooperation, for example, the handling of price regulations (Jacobsen et al., 2014) or potential distortions of cross-border supply security (Federal Ministry for Economic Affairs and Energy, 2020) as well as the regulation of interconnectors (Consentec research consortium, 2018) should be mentioned. In the area of existing incentive structures, Article 6 and Article 11 of EU Directive 2009/28/EC (2009) provide further opportunities to explore the application of the NO criteria. The lack of further concrete guidance for action within TMO states regarding regional cooperation may be due to the lack of cross-border cooperation in the sense of the EU cooperation mechanisms analysed in this paper (Caldés et al., 2019). It remains to be seen to what extent this lack of real cooperation scenarios will also take hold within the TMO states and negate a cooperative energy market accordingly. In particular, the fact that the TMO states could, however, focus on a non-cooperative achievement of their respective RES targets (Ragwitz et al., 2012) could, however, indicate this and would consequently complicate the integration of the NO rules and criteria explored in this work.

7.3 Implementation of economic policy reforms

To answer the question of reform delays for a European renewable energy market, we used the theory of economic policy reform to analyse past efforts and delays. In the economic reform delay model, the risk of the closing reform window, the status quo costs and the reform cost allocation, among others, are decisive for the duration of the reform delay. It could be shown that in the TMO electricity market the lack of a closing reform window argues against a fast reform implementation. However, exceeding the time frame increases the status quo costs when penalties become due. The status quo costs are already high today and will increase in the future. In theory, this argues in favour of rapid reform implementation.

In the TMO, on the other hand, a delay in reform can result from cost sharing. By waiting, a higher cost sharing by the other countries can be achieved. The problem was discussed using the situation in Switzerland as an example. However, it can be applied to all countries that have to bear a disproportionate share of the costs due to reform measures. The countries of the TMO thus have an incentive to delay their consent to reform measures in order to increase their payout and realise an improvement in their benefits. All actors remain in the status quo. Although the EU countries have already spoken out in favour of a comprehensive integration of the electricity markets in 2011 (EC, 2011), and Switzerland has also been negotiating an electricity agreement with the EU since 2007 (UVEK, 2017), the comprehensive implementation of decisive reform measures has not yet occurred. This supports the thesis that the costs of the status quo are currently not yet the decisive factor for reform implementation and that asymmetric sharing of reform costs in the TMO represents a significant obstacle to reform.

It could be shown that individual uncertainty about the effects of the reform measures is relevant in the TMO. Therefore, it is difficult to determine ex ante who will be among the winners or losers. A differentiation should be made between the various reform measures: In the case of infrastructure projects, uncertainties arise even if the projects are purely national. The cross-border impact of expansion projects in the electricity market adds cross-border uncertainties about the cost-benefit distribution between countries. They complicate the reform situation. However, it is possible to introduce compensation mechanisms to offset potential losses so that the expected and actual net benefits are positive. In the case of a cross-border organisation of security of supply, uncertainty only arises through cross-border cooperation. In the case of balanced self-supply, cross-border insecurity would not exist. Since the national energy supply is a critical infrastructure, this is particularly relevant for the countries. The risk of a power blackout is assessed higher by the countries in the case of cross-border cooperation and the expected loss in the case of non-fulfilment of supply agreements is very high. The countries will therefore favour solutions that do not make them dependent on foreign countries for security of supply and where they can avoid uncertainty. The energy declaration of the Franco-German Council of Ministers (2015) explicitly emphasises that security of supply should remain a purely national matter. In this respect, joint capacities and a joint expansion of renewable energies can also only be realised to the extent that national supply security is not affected.

In the model of reform resistance, in the case of individual uncertainty, remaining in the status quo is more likely than a successful implementation of reform measures (status quo bias). Although there are opportunities and advantages for the countries in the association, one must assume that due to the potentially high costs and individual uncertainty, the expected net benefit of the reform measures will be negative if the measures are fully implemented as a reform package. In this case, countries will expect not to switch from sector L to sector W. Individual uncertainty about the actual net benefits can consequently be a significant barrier to the implementation of reform measures in the TMO.

Based on the political loser model, we can assume that the difference in probabilities of political power retention in the TMO countries is high, i.e. the probability of political power retention is higher when blocking than when tolerating the reform. At the same time, the loss for the monopolist is high if it relinquishes power. This speaks for a blockade of the reforms by the political losers. One argument against a blockade, however, is that the costs of the blockade are high. However, current delays in the completion of the internal electricity market as well as delays in the conclusion of an electricity agreement with Switzerland indicate that the costs of the blockade are not yet high enough in relation to the political losses. Therefore, the inequality that is decisive in the model for a reform blockade can be regarded as fulfilled. Political losers are to be regarded as a decisive obstacle to reform in the TMO.

In the reform delay model, the smaller the difference between the active and passive payout, the shorter the delay. In the case of equality, direct reform occurs because waiting is not worthwhile (Alesina & Drazen, 1991). Therefore, it is important to consider cost sharing in the reform design. A reduction of the difference can be achieved by taxing the reform winners (α decreases) and / or by compensating the relative reform losers (Schröder, 2006). Thus, a compensation mechanism is needed through which an asymmetric cost-benefit distribution is prevented and the reform programme is made fairer. Furthermore, it is important to determine the cost allocation and compensation ex ante, so that no other allocation can be achieved by waiting. One way to achieve this is to allocate the costs to be borne among the countries in proportion to the benefits achieved. This determines from the outset how the costs will be distributed among the countries involved. However, proportional cost sharing can be difficult to implement. Not all countries have the same understanding of costs and benefits, and it is important to apply a commonly accepted costing principle to cross-border investments. In addition, existing uncertainties should be adequately dealt with (Meeus & He, 2014). In addition, the following difficulties can arise when introducing compensation payments: By taxing the (relative) reform winners, additional costs may arise due to a distorting effect of taxation. The desired result can no longer be achieved and the efficiency of the mechanism is no longer given; Asymmetric information about actually realised losses (even if only relative losses occur) can lead to compensation payments being too high. This leads to overcompensation, which is not optimal (Roland, 2002).

According to a survey by Consentec (2018), with existing compensation mechanisms at EU level, states have incentives to estimate the national benefits as low as possible in order to reduce their own cost sharing. These issues should be taken into account in the reform design. At the EU level, cross-border cost sharing was initiated in Regulation 347/2013 (CBCA) to promote the cross-border expansion of electricity grids. In principle, this instrument is intended for projects in which participating countries achieve net losses. Accordingly, compensation of relative losers is not explicitly taken into account (Energy Community, n.d.). However, there are examples where cross-border cost sharing has successfully taken place even though no net losers were expected ex ante. For example, Latvia and Lithuania agreed to jointly finance the construction of a gas pipeline in Lithuania and also to jointly implement a project in Latvia (Meeus & Keyaerts, 2015). Lithuania justified its contribution with emerging synergy effects. Poland and the Czech Republic justified a cross-border compensation mechanism by saying that it ensures the stability of the investment and the commitment of the expansion on both sides of the border. Sweden and Norway also used a cost-benefit analysis to enable cross-border cost sharing. Norway achieved through compensation payments to Sweden that the country completed the expansion of a cross-border line faster and thus Norway was able to reduce its costs of the status quo. The transmission system operators of both countries agreed on a joint expansion contract for this purpose. Mees and He assume that the amount of the payments is based on the costs of a delay and the additional costs for Sweden due to a faster expansion (Meeus & He, 2014).

Consequently, cost-sharing arrangements can contribute to the realisation of projects with asymmetric cost-benefit impacts. Mechanisms for cross-border cost sharing should therefore also be applied and institutionally anchored in the TMO for the case in which no net losses occur but there is a delay due to asymmetrically distributed costs and benefits. In the reform delay model, it is also expedient to introduce binding time limits by which the reform measures must be implemented. However, this gives rise to the already discussed problem that the reform window cannot really close. Moreover, there is no body in the TMO itself that checks compliance with the time frame and at the same time has the competence to impose penalties. Regulations on this could be made at EU level, as penalty payments can be enforced at this level (EC, n.d.b). These would have to be set at such a high level that the status quo costs would increase considerably. Reform implementation then becomes all the more urgent.

Based on the model of reform resistance, the questions arise as to how uncertainty can be reduced so that winners of the reform already expect a positive benefit ex ante (□□□>0) and how actual losers of the reform can be compensated so that they achieve a positive net benefit. To overcome reform constraints, Roland (2002) suggests several strategies: The design of reform packages that include compensation for absolute reform losers, measures that provide for only partial implementation of reforms, and the introduction of institutions that make compensation credible. In the case of infrastructure projects with an uncertain and potentially highly asymmetric cost-benefit distribution, compensation mechanisms are to be initiated on the basis of the model application so that countries do not incur absolute losses and reform blockades can be ruled out. Therefore, the compensation of absolute losers will be discussed in this section. Countries that are net losers with a high probability can be compensated by net gainers. Meeus and He refer to this as "minimum compensation" (Meeus & He, 2014). A strict rejection of cross-border projects can thus be prevented. However, if only the absolute losses are compensated, it cannot be ensured that there is no incentive to delay, as costs and benefits can still be asymmetrical. This contrasts with compensation that puts costs and benefits in proportion for all countries. Problems can arise with compensation payments, as has already been examined. Besides efficiency losses due to taxation and possible overcompensation of reform losers, it can also be difficult to credibly communicate compensation payments. This requires institutions that safeguard the transfer payments (Roland, 2002). For example, the

EU could act as an external actor in the TMO to ensure that compensation is secured. In order to prevent reform blockades in the expansion of a cross-border, sustainable electricity market in the TMO, potential absolute losses should therefore be identified and compensation mechanisms credibly agreed so that all countries expect a positive net benefit ex ante and ex post.

Another way to prevent reform blockades and reduce uncertainty is to implement partial reforms. This can be beneficial because initial learning effects about the possible effects of the measures can be achieved and the costs of a return to the status quo are not yet so high. Compensation payments are also lower with partial reforms (Roland, 2000). The countries of the TMO could first decide only to jointly develop renewable energy and organise some of the capacity together without organising security of supply across borders. Uncertainty regarding energy supplies from abroad is less crucial in this case than in the case of comprehensive reform implementation, since security of supply is not affected. However, efficiency losses may also occur in partial reform implementation and not all the benefits of a full reform may be achieved (Roland, 2000). Consequently, if the development of a cross-border electricity market in the TMO is limited to cross-border cooperation regarding renewable energy development, not all cost benefits can be achieved. At the same time, it is important to note that projects may be complementary and the resulting costs and benefits can only be correctly determined if these complementarities are taken into account (Meeus & He, 2014). Therefore, it may again be more beneficial to implement the reform package holistically. In their study, Rechlitz et al. (2014) calculated that only if the cooperation measures considered are implemented in their entirety do all countries fare better. If individual measures are implemented, there are absolute losses for Switzerland and Germany (Rechlitz et al., 2014). Consequently, there are advantages and disadvantages from the above reform designs.

In addition, there are further measures that can contribute to the reduction of uncertainty. According to the EU Commission (2013), the reluctance of member states regarding cross-border cooperation mechanisms will decrease if the direct and indirect advantages and disadvantages are identified more precisely and explicitly mentioned in a cooperation agreement. At this point, it can be decided whether cooperation is worthwhile or not and which transfer payments will be necessary (EC, 2013). To avoid uncertainties, it is important that countries clearly communicate their energy policy strategies. Agora and IDDRI (2018) argue that Germany and France should cooperate closely regarding their national strategies, especially with regard to the operation of conventional power plants, and set binding targets. More cross-border coordination in this regard is a necessary condition for cooperating countries to voice objections before national decisions are made. Issues concerning an adequate and reliable power supply in the region can be discussed in a committee that gathers representatives from all participating countries and from different sectors of the electricity market. A purely national and one-sided perspective can thus be avoided and complementarities can be better exploited (Bössner, 2015).

In order to reduce uncertainty about actual electricity deliveries, the EU Commission (2013a) points out that cross-border deliveries should not be dependent on the exporting country achieving a surplus in electricity generation. Furthermore, as already discussed, the impact of projects on security of supply is insufficiently taken into account in CBA procedures. This can lead to less efficient, suboptimal decisions. It is therefore recommended to include approaches that allow for monetisation of security of supply impacts (Consentec, 2018). In addition, increasing public acceptance can help to reduce uncertainty. For this, a transparent and public presentation of all identified costs and benefits is important. Above all, it should be made clear that national potentials and goals are also promoted through cooperation (EC, 2013). Particularly with regard to grid expansion measures, certain measures can be suitable for increasing acceptance. These include compensation mechanisms, the laying of underground cables and the early involvement of all relevant stakeholders (Consentec, 2018). France can serve as a positive example. For example, there is a comprehensive public participation process there. Planning and approval steps are carried out with the participation of the affected stakeholders. In addition, the French transmission system operator RTE is obliged to co-finance sustainable projects in affected regions (Consentec, 2018).

The application of the political loser model has shown that loss of political influence can also be a blocking reason in the TMO. At this point, however, it is quite difficult to derive starting points for a reform design that is helpful for the expansion of the cross-border electricity market in the TMO. One suggestion would be to further unbundle politics and energy companies so that the probability of retaining power in case of a blockade decreases and thus the difference decreases. More powers in energy policy could be shifted to the EU level to also take power away from politicians. However, these efforts are difficult to implement because it is again a matter of giving up political power, which was identified in the model as a reason for blocking reform. The EU states have to decide on this at EU level (Knodt, 2019). A transfer of power cannot credibly be linked to compensation agreements (Acemoglu & Robinson, 2000).

Despite the assumption that an energy alliance is fundamentally beneficial for all participating states in the long term, problems can arise during the agreement process. Each state tries to follow the rational behaviour of gaining the greatest possible benefit and thus the lowest possible costs. There is a danger that reform measures will not be implemented, as each state tactics to be able to apply free-rider behaviour. Currently, there is a lack of the necessary decision-making power at the supranational level to counteract this problem. For although the implementation of the reform measures is associated with costs for each state, non-implementation represents far greater costs in the future, as the long-term benefits of an energy alliance cannot be reaped. Binding contracts, for example, which sanction the defective behaviour of the parties and thus make it unprofitable, can contribute to the solution. Consequently, a socially efficient equilibrium could be created.

7.4 Acceptance of renewable energies and participation of local actors

The collected data showed that in all three nations experience with, as well as knowledge of renewable energy sources and plants contribute to a higher acceptance of RE. This applies to both the support (passive acceptance) for the construction of renewable energy plants and the financial participation (active acceptance) with regard to RE plants. The lower financial willingness to participate of the French respondents compared to the participants of the other two countries is in line with the real willingness to participate in RE projects in France. With regard to the engagement of local actors, for example in the context of energy cooperatives, in RE projects, France is clearly behind Germany and Switzerland (DGRV, 2021; Kahla et al., 2017; Rivas et al., 2018; Sebi & Vernay, 2020). While Switzerland has a similar number of energy cooperatives as Germany, measured by its population, citizen energy models of any kind are hardly widespread in France (Rivas et al., 2018; Sebi & Vernay, 2020). This can be attributed to the more favourable institutional framework in Germany and Switzerland. As previously described, the energy policy frameworks in Switzerland and Germany are comparable; similar financial incentive mechanisms have been created to mobilise the willingness of local actors to participate. Improving the institutional framework should thus play a central role in activating citizens' financial willingness to participate. Currently, attempts are being made in France to break down institutional barriers and establish direct financial investments with so-called crowdfunding models (Drogosch, 2018). In France, for example, the establishment of priority access to the grid for RE plants could ensure that the financial commitment on the part of the population is increased (Schumacher et al., 2019). It also became apparent that both knowledge and experience have a stronger influence on active acceptance in the form of financial participation than the mere endorsement of a RE plant in the immediate neighbourhood. This once again emphasises the immense importance of the two acceptance factors for the success of the energy transition and the expansion of RE with the inclusion and active participation of private actors.

Furthermore, it could be shown that the acceptance factor knowledge has a stronger influence on the attitude towards the construction of a RE plant in the immediate vicinity than already existing experience. Knowledge had a significant influence on most forms of renewable energy, whereas experience had no significant influence on the attitude of the respondents, with the exception of wind energy plants. This result highlights that lack of information can be an underlying factor in lack of uptake and that actively educating local residents about renewable energy technologies is essential for the expansion of RE installations. The data suggests that the financial participation willingness of respondents in all countries for RE projects is generally higher than the actual participation in the respective countries. The potential for actual participation seems to be anchored, so that one should expect that with the appropriate measures, the financial participation of the population can be increased. There are many opportunities for political actors to offer appropriate participation opportunities in order to reach those citizens who, for example, do not participate financially and thus actively in RE projects due to a lack of information about RE (Schumacher et al., 2019). The lack of information can also be related to the investment opportunity itself. Langer et al. (2017) emphasise that it is possible to increase the willingness to invest in RE projects if financial institutions better inform the population about investment opportunities in the RE sector.

The present study focused on the general perception of respondents regarding renewable energy technologies and their implementation at the societal level. Thus, like most studies on the acceptance of RE, this study took place at the level of socio-political acceptance (also referred to as societal acceptance) and is purely attitudinal (Ohlsen, 2018; Schäfer & Keppler, 2013). As outlined in this paper, the socio-political acceptance level is only one of three dimensions of social acceptance as defined by Wüstenhagen et. al (2007). Against this background, the present study is thus unable to show the reciprocal relationships between socio-political acceptance, market acceptance and local acceptance. Moreover, it cannot provide any information on the local acceptance of specific RE projects.

The socio-political dimension, which primarily captures social attitudes towards RE, can be assigned to the attitude level (Schäfer & Keppler, 2013 in Schumacher et al., 2019). However, for the successful completion of the energy transition and the associated expansion, active participation of the actors is required in addition to passive advocacy, i.e. a positive attitude, which would be linked to an action dimension. In the course of this survey, the respondents' willingness to participate in RE projects was queried several times. The attitude-related acceptance that was asked in this survey may contain an intention to act, but says nothing about the actual success of an action (Schäfer & Keppler, 2013). It can be assumed that the questioned willingness to actively participate does not reflect the actual participation.

Hildebrand and Renn (2019) emphasise that there is a divergent understanding of acceptance in research and practice; in practice, acceptance is often considered without the action dimension and passive advocacy is understood as acceptance. This limitation must be taken into account when interpreting purely attitude-based acceptance research. It is also conceivable that there are test persons who have expressed their willingness to participate financially and would actually participate financially, but simply do not have the necessary financial means to do so. There was also an unfavourable ratio in terms of group size of test persons with and without experience of various specific forms of renewable energy. Furthermore, as previously explained, there was a large discrepancy between the average age of the respondents from Switzerland and the average age of the Swiss population as a whole. The intentions and attitudes of the younger part of the Swiss population are better represented in this study than those of the older population. These two limitations regarding the sample should be taken into account.

Despite its limitations, the present study offers important data with regard to acceptance research in a cross-national context. There are few studies in the field of social acceptance research that use empirical data to make regional or national comparisons (Schumacher et al., 2019). The study carried out joins the group of research papers by Schumacher et al. (2019), Schumacher and Schultmann (2017), Jobert et al. (2007) or also Warren et al. (2005), which have also investigated the social acceptance of RE across countries (Schumacher et al., 2019). It was shown that it can be assumed that the questioned financial willingness to participate is higher than the actual willingness to participate. For the energy transition to succeed, it is still necessary to mobilise the financial willingness of private actors to participate and to further close the gap between hypothetical and real willingness to participate. Based on the national comparisons, it could be determined that Germany and Switzerland showed a higher willingness to participate than France. In addition to the aforementioned political framework conditions, which are relatively better in Germany and Switzerland, the lack of experience and knowledge of the French population is also responsible for the national differences. The results of this study suggest that the willingness to participate financially can be increased through targeted information offers. The knowledge gained offers countries many starting points on how it is possible to continue to increase passive and active acceptance towards RE installations in the future.

Chapter 8. Conclusion

Despite the many national differences, notably in regard to the energy mixes, regulatory, economic and societal frameworks, all three countries, Germany, France and Switzerland, have set the target of reaching carbon neutrality by 2050 at most (IEA, 2021a; BFE, 2020; Bundesregierung, n.d.). Moreover, it can also be observed that their strategies of achieving that target all rely, among others, on considerably increasing the renewable energy sources (RES) in their energy mixes.

The total energy demand in the Upper Rhine Region was estimated to be 212 TWh by a feasibility study performed on the same study area in 2022. According to the results of WP2, the total technical potential for energy generation from RES estimated to be 359 TWh/yr is large enough to cover this demand. However, the technical potential is limited by the economic and feasible potential, as explained in Chapter 2. Moreover, this potential is also limited by a variety of other factors such as land use competition due to food production, environmental impacts, landscape aspects, societal acceptance, and economic framework. The importance of calculating the technical potential lies in the support of better frame conditions which could be facilitated by integrating the different stakeholders such as citizens and enterprises in the process which was the main focus of WP4. (Koch (Ed.), 2022) Specifically, WP4 analysed the socio-cultural conditions for the development of a renewable energy system in the region by focusing on the favourable conditions that allow the regional stakeholders to cooperate across national borders and the importance of involving citizens in the regional decision-making process related to renewable energy.

The study performed by WP2 focused on finding the usable area where the propagation of RES projects could take place. In the case of WP2, the estimation of the potentials was mostly related to the spatial availability of land area and the calculated potential was presented as a yearly estimate. On the other hand, the penetration of RES into the electricity grid requires a certain degree of flexibility and storage facilities as explored in the research of WP3. Because of the intermittent character of RES, WP3 studied the hourly variation of the electricity demand in the URR and simulated different scenarios that included various combinations of storage and RES in the future energy supply to find the most optimal combination and also to analyse possible future regional energy systems. Additionally, in order to handle the increasing demand for electricity and renewables, the regional, national and transnational grid needs to be well equipped; for this reason, WP6’s research sheds light on the need to expand the grid across borders especially considering the poorly developed coupling points of the member states because of the somewhat subordinate role that electricity exchanges with neighbouring countries have played until now. Further, WP6 tackled the hindrances that grid development projects continue to face despite the pressing need for increasing renewable generation capacity. Additionally, as was emphasised in the introduction, demand side management and digitalization are set to add security to the future energy system through smart grids and metres for example. Cyberattacks constitute a substantial security threat nowadays; therefore, the focus of WP7 was on data security and countering the increasing cyber attack threats in one aspect of digitalization which is smart grids.

On another note, among the biggest obstacles faced in this project was the availability and uniformity of data across the border regions owing to the structural differences of each country. The trinationality of the region also contributes to major differences in the legal and regulatory structure of the three countries. Therefore, WP5’s research addressed the variety of legal obstacles and gave many possible solutions for reducing these obstacles in order to facilitate the scale-up and development of renewable energy technologies. WP5 also analysed the impact of European and national regulations that are related to RES on their development in each of the three countries.

Finally, the main goal of the project as defined previously was to "examine the synergies arising from complementary generation, demand and storage capacities as well as from cross-border energy initiatives in the TMO, with a view to developing policy recommendations assisting with the energy transition." It is clear that the now completed research of the RES-TMO project's working packages was interconnected and holistic. More importantly, the packages through their delivered outputs have succeeded in providing an overview of different, relevant topics centred around RE. These include: the renewable energy potentials and their involvement in the different possible scenarios for the regional future energy system along with the current local atmosphere in terms of legal and regulatory obstacles on a regional, national and European level for grid and renewable energy project development, threats to the grid, energy and data security through cyber attacks and the social acceptability of RE projects, and citizen involvement in the decision making process.

As a conclusion, it was stated by the IEA (2021b) that "governments can further accelerate the growth of renewables by addressing key barriers, such as permitting and grid integration challenges, social acceptance issues, inconsistent policy approaches, and insufficient remuneration." The RES-TMO project has addressed many of the aforementioned ideas for accelerating the growth of renewables, in a tri-national regional context, in the hopes of making a difference in not one but three countries and providing an ideal model region for future cross-border cooperation projects.

List of Authors

Editors: Barbara Koch, Ines Gavrilut, Zeina Najjar, Adem Ugurlu, Kristina Izmailova

Chapter 1:

Ines Gavrilut, Zeina Najjar

Prof. Barbara Koch

Chapter 2:

Zeina Najjar, Felix Kytzia, Prof. Barbara Koch

Johannes Miocic, Martin Kügel

Chapter 3:

Joris Dehler-Holland

Bushra Canaan, Djaffar Ould Abdeslam

Marco Guevara, Adrien Barth, Alain Clappier, Nadège Blond

Chapter 4:

Bushra Canaan, Djaffar Ould Abdeslam

Chapter 5:

Marie Mangold, Sophie Henck, Philippe Hamman

Chapter 6:

Melis Aras, Elisabeth Lambert, Sophie Gambardella, Theresa Hüsch, Jens-Peter Schneider

Chapter 7:

Bianca Blum, Dominik Schröder, Marcel Franke, Bernhard Neumärker.

Conclusion:

Zeina Najjar

List of Abbreviations

AEY	Annual Energy Yield
AI	Artificial Intelligence
ASEC	Swiss Association for Citizen Energy
CBCA	Cross-Border Cost Allocation
CCGT	Combined Cycle Gas Turbines
CECs	Citizen Energy Communities
CEI	Community Energy Initiatives
CEM	Climate and Energy Model
CHP	Combined Heat and Power Plants
CLC	CORINE Land Cover
CPS	Cyber Physical System
CSIRTs	Computer Security Incident Response Teams
DERs	Distributed Energy Resources
DSP	Digital Service Providers
DSOs	Distribution System Operators
EDF	Electricité de France
EEA	European Energy Award
EEG	Renewable Energy Act
EGS	Enhanced Geothermal Systems
ENISA	The European Union Agency for Cybersecurity
EOM	Energy Only Market
ETS	Emissions Trading System
EV	Electric Vehicles
GDPR	General Data Protection Regulation
GECLER	Grand Est Citoyen et Local d'Énergies Renouvelables
GEEV	Grenzüberschreitende-Erneuerbare-Energien-Verordnung
GHGs	Greenhouse Gas Emissions
GIS	Geographical Information System
GM	Ground Mounted
H2	Hydrogen
ICPE	Installations Classified as Environmental Protection
ICPP	Integrated Climate Protection Programs
ICT	Information and Communication Technologies

IEA	International Energy Agency
IoT	Internet of Things
LEM	Local Electricity Markets
MS	Mobilité Spaciale
NIS	Network and Information Security
NO	New Ordoliberalism
NPP	Nuclear Power Plant
NREAP	The National Renewable Energy Action Plan
OES	Operators of Essential Services
ORG	Oberrheingraben
PERSEUS	Programme-package for Emission Reduction Strategies in Energy Use and Supply-Certificate Trading
PtG	Power to Gas
PV	Photovoltaic
RA1	Research Group 1
RE	Renewable Energy
RECs	Renewable Energy Communities
REPM	Regional Energy Planning Model
RES	Renewable Energy Sources
RLS	Regional Leaders Summit
RRF	Recovery and Resilience Facility
SNBC	Stratégie Nationale Bas Carbone
SWOT	Strengths, Weaknesses, Opportunities and Threats
TAC	Total Annual Cost
TMO	Trinational Metropolitan Region Oberrhein
TSOs	Transmission System Operators
URR	Upper Rhine Region
WPD	Wind Power Density
WP 2	Work Package 2
WP 3	Work Package 3
WP 4	Work Package 4
WP 5	Work Package 5
WP 6	Work Package 6
WP 7	Work Package 7

WSMS	Wind Speed Wind Shear

List of Figures

List of Tables

Literature

Chapter 1:

Avere et al. (2020). Open letter Decarbonising the EU building stock with available solutions and no direct use of hydrogen. Retrieved October 24, 2022., from https://euase.net/wp-content/uploads/2021/01/210120_Open-letter_Timmermans_hydrogen.pdf

Bataille, C., Åhman, M., Neuhoff, K., Nilsson, L. J., Fischedick, M., Lechtenböhmer, S., Solano-Rodriquez, B., Denis-Ryan, A., Stiebert, S., Waisman, H., Rahbar, S., Sartor, O. (2018). A review of technology and policy deep decarbonization pathway options. Journal of Cleaner Production, 187 (2018), 960-973. Doi: 10.1016/j.jclepro.2018.03.107

Bowen, T. (2019). CIFF MOOC 3. EdX course material: Incorporating Renewable Energy in Electricity Grids from Imperial College London online learning initiative (10/2018 - 02/2019).

Bundesamt für Energie – BFE (2020). (June, 2019). Schweizerische Statistik der Erneuerbaren Energien 2019, Bundesamt für Energie – BFE (2020). Bern. https://pubdb.bfe.admin.ch/de/publication/download/9765.

Bundesregierung (n.d). Bundesregierung, Retrieved June 2022 from: https://www.bundesregierung.de/breg-de/themen/klimaschutz/klimaschutzgesetz-2021-1913672 [Webpage]

Chen C., Bing X., Guotian C., Heiko T., & Stueckrad S. (2019). Comparing the energy transitions in Germany and China: Synergies and recommendations. Energy Reports (2019), 5, 1249-1260. doi: https://doi.org/10.1016/j.egyr.2019.08.087

Cooke, P. (2011). Transition regions : Regional – national eco-innovation systems and strategies. Progress in Planning, 76(3), 105–146. https://doi.org/10.1016/j.progress.2011.08.002

Duch-Brown, N. & Rossetti, F. (2020). Digital platforms across the European regional energy markets, Energy Policy, 144 (October 2019). https://doi.org/10.1016/j.enpol.2020.111612

European Commission (2018a). Commission Welcomes Political Agreement on Conclusion of the Clean Energy for all Europeans Package, Press release, 18 December 2018, Brussels, available at: https://ec.europa.eu/commission/presscorner/detail/en/IP_18_6870

European Commission (2018b). Clean Energy for all Europeans, official website, available at: https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/clean-energy-all-europeans

European Commission (2019). The State of the Energy Union Explained, Fact Sheet, 9 April, Brussels, available at: https://ec.europa.eu/commission/presscorner/detail/en/MEMO_19_1875

European Commission (2020). How Can Your City Become... 100% Renewable?, Luxembourg, Publications Office, available at: https://data.europa.eu/doi/10.2779/212569.

European Commission (2021). State of the Energy Union 2021 – Contributing to the European Green Deal and the Union's recovery. Brussels, 26.10.2021. COM(2021) 950 final. Available at: https://energy.ec.europa.eu/system/files/2021-10/state_of_the_energy_union_report_2021.pdf

European Commission (2022a). 2030 Renewable energy targets, official website, available at: https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-targets_en

European Commission (2022b). A European Green Deal. Striving to be the first climate-neutral continent, official website, available at: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

Gerbelová, H., Spisto, A., & Giaccaria, S. (2021). Regional Energy Transition: An Analytical Approach Applied to the Slovakian Coal Region. Energies, 14, 110. https://doi.org/10.3390/en14010110

Gils, H. C., Simon, S., & Soria, R. (2017). 100% Renewable energy supply for Brazil-The role of sector coupling and regional development. Energies, 10(11). https://doi.org/10.3390/en10111859

Goers, S., Rumohr, F., Fendt, S., Gosselin, L., Jannuzzi, G. M., Gomes, R. D. M., … Wolvers, R. (2021). The Role of Renewable Energy in Regional Energy Transitions : An Aggregate Qualitative Analysis for the Partner Regions Bavaria , Georgia , Qu é bec , S ã o Paulo , Shandong , Upper Austria , and Western Cape. Sustainability , 13(1), 76; https://doi.org/10.3390/su13010076

Henning, H.-M., Palzer, A. (2015). Was kostet die Energiewende? Wege zur Transformation des deutschen Energiesystems bis 2050. Fraunhofer-Institut für Solare Energiesysteme ISE, Freiburg. https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Fraunhofer-ISE-Studie-Was-kostet-die-Energiewende.pdf.

Hoolohan, C., Mclachlan, C., & Larkin, A. (2019). Technological Forecasting & Social Change "Aha" moments in the water-energy-food nexus : A new morphological scenario method to accelerate sustainable transformation. Technological Forecasting & Social Change, 148 (August), 119712. https://doi.org/10.1016/j.techfore.2019.119712.

Hoppe, T., Miedema, M. (2020). A Governance Approach to Regional Energy Transition: Meaning, Conceptualization and Practice. Sustainability, 12, 915. doi:10.3390/su12030915.

IEA (2019). Integrating Power Systems Across Borders – Analysis, Technology report, June, Retrieved August 25, 2021 from https://www.iea.org/reports/integrating-power-systems-across-borders.

Limpens G., Jeanmart H., Moret S., Guidati G., Li X., Maréchal F. (2019). The Role of Storage in the Swiss Energy Transition, Proceedings of the 32nd International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, 1 (1): 761–774. https://dial.uclouvain.be/pr/boreal/object/boreal:218561.

Papapetrou M., Kosmadakis G., Cipollina A., La Commare U., & Micale G. (2018). Industrial waste heat: Estimation of the technically available resource in the EU per industrial sector, temperature level, and country. Applied Thermal Engineering, 138, 207-216. https://doi.org/10.1016/j.applthermaleng.2018.04.043.

Schiffer H. W., Trueby J. (2018). A review of the German energy transition: taking stock, looking ahead, and drawing conclusions for the Middle East and North Africa. Energy Transitions, 2, 1–14. https://doi.org/10.1007/s41825-018-0010-2.

Serafino, P. (2022). France Coal-Fired Power Plants Get Short-Term Right to Burn More. Bloomberg. https://www.bloomberg.com/news/articles/2022-02-06/france-coal-fired-power-plants-get-short-term-right-to-burn-more?leadSource=uverify%20wall

TRION-climate e.V. (2019). Trinationaler Klima- und Energiebericht. Treibhausemissionen, Energieverbrauch, Erneuerbare: Umsetzung der Klima- und Energieziele am Oberrhein, Kehl, available at: https://trion-climate.net/fileadmin/Aktivitaeten/Trion_Studien/Energiebericht/Trinationaler_Klima-_und_Energiebericht_TRION_Nov._2019_final.pdf.

Umweltbundesamt (2020). Umweltbundesamt. Retrieved: October 2020 from https://www.umweltbundesamt.de/.

Umweltbundesamt (2020a). 'Emissionsquellen', available at: https://www.umweltbundesamt.de/themen/klima-energie/treibhausgas-emissionen/emissionsquellen.

Umweltbundesamt (2020b). 'Energiebedingte Emissionen', available at: https://www.umweltbundesamt.de/daten/energie/energiebedingte-emissionen.

Umweltbundesamt (2020c). 'Treibhausgasminderungsziele Deutschlands', available at: https://www.umweltbundesamt.de/daten/klima/treibhausgasminderungsziele-deutschlands.

Umweltbundesamt (2020d). 'Erneuerbare Energien in Deutschland 2019', available at: https://www.umweltbundesamt.de/publikationen/erneuerbare-energien-in-deutschland-2019.

Victoria M., Zhu K., Brown T., Andresen G B., Greiner M. (2019). The Role of Storage Technologies Throughout the Decarbonisation of the Sector-Coupled European Energy System. Energy Conversion and Management, 201, 111977. https://doi.org/10.1016/j.enconman.2019.111977.

Weigel P.l, Fischedick M. (2019). 'Review and Categorization of Digital Applications in the Energy Sector'. Applied Sciences, 9 (24): 5350. https://doi.org/10.3390/app9245350.

Weiss O., Pareschi G., Georges G., Boulouchos K. (2021). The Swiss Energy Transition: Policies to Address the Energy Trilemma, Energy Policy, 148,111926, https://doi.org/10.1016/j.enpol.2020.111926.

Zimm, C., Goldemberg, J., Nakicenovic, N., & Busch, S. (2019). Is the renewables transformation a piece of cake or a pie in the sky? Energy Strategy Reviews, 26, 100401. https://doi.org/10.1016/j.esr.2019.100401.

Chapter 2:

Axpo (2018). Water's Power. Available Online: https://www.axpo.com/ro/en/magazine/renewable-energy/the-power-of-the-river.html

Banque des Territoires (juin 2010). La micro-hydraulique a de l'avenir en Alsace. https://www.banquedesterritoires.fr/la-micro-hydraulique-de-lavenir-en-alsace

Bayliss C.R. & Hardy B.J. (2012). Chapter 3 - Substation Layouts, Transmission and Distribution Electrical Engineering 4, 93-119. 10.1016/B978-0-08-096912-1.00003-4

Bhattacharya S. (2017). Smart Transformers Will Make The Grid Cleaner and More Flexible. IEEE Spectrum.

https://spectrum.ieee.org/smart-transformers-will-make-the-grid-cleaner-and-more-flexible

Boring N. (2019, Dec. 4). France: Law on Energy and Climate Adopted. Library of Congress. https://www.loc.gov/item/global-legal-monitor/2019-12-04/france-law-on-energy-and-climate-adopted/

Britannica (2021, 23 Jul). Transformer. Encyclopedia Britannica. Retrieved 26 October 2021 from https://www.britannica.com/technology/transformer-electronics.

EDF (n.d.). Les Aménagements Hydroélectriques Du Rhin. EDF. https://www.edf.fr/sites/default/files/Hydraulique/Alsace-Vosges/documents/les_amenagements_hydroelectriques_du_rhin_franco-allemand.pdf

EEA, Lechner Knowledge Center (Lechner Tudásközpont) & Umweltbundesamt (2019). Updated CLC Illustrated Nomenclature Guidelines.

https://land.copernicus.eu/user-corner/technical-library/corine-land-cover-nomenclature guidelines/docs/pdf/CLC2018_Nomenclature_illustrated_guide_20190510.pdf

EEG (2021). Erneuerbare-Energien-Gesetz [Renewable Energy Sources Act], Part 2, § 8 et seq.. https://www.gesetze-im-internet.de/eeg_2014/

EnBW (n.d.). Hydropower. EnBW. https://www.enbw.com/renewable-energy/wasserkraft/

Enedis (n.d.). Se raccorder ou modifier une installation. Enedis. https://www.enedis.fr/se-raccorder-ou-modifier-une-installation

Fang S. J., Roy S., & Kramer J. (1999). Transmission Structures. Structural Engineering Handbook. http://freeit.free.fr/Structure%20Engineering%20HandBook/15.pdf

Fraunhofer Institute for Solar Energy Systems ISE (Ed.) (2020). Agrivoltaics: Opportunities for Agriculture and the Energy Transition.

https://www.ise.fraunhofer.de/en/publications/studies/agrivoltaics-opportunities-for-agriculture-and-the-energy-transition.html

Grau L., Jung C. & Schindler D. (2017). On the Annual Cycle of Meteorological and Geographical Potential of Wind Energy: A Case Study from Southwest Germany. Sustainability , 9, 7, 1169. 10.3390/su9071169

Guénaire M., Dufour T., George E., Assayag S., & Nouel G.L. (2020). Electricity Regulation in France: overview. Thomson Reuters Practical Law. https://uk.practicallaw.thomsonreuters.com/7-629-7567?transitionType=Default&contextData=(sc.Default)&firstPage=true

Huld T. (2017). 'PVMAPS: Software Tools and Data for the Estimation of Solar Radiation and Photovoltaic Module Performance Over Large Geographical Areas'. Solar Energy, 142, 171-181. 10.1016/j.solener.2016.12.014.

IEA (n.d.). International Energy Agency. Retrieved October 2021 from https://www.iea.org/countries/

Jäger T., McKenna R. , Fichtner W. (2016). The Feasible Onshore Wind Energy Potential in Baden-Württemberg: A Bottom-up Methodology Considering Socio-Economic Constraints. Renewable Energy, 96, 662–675. 10.1016/j.renene.2016.05.013.

Jung C. & Schindler D. (2017). Development of a Statistical Bivariate Wind Speed-Wind Shear Model (WSWS) to Quantify the Height-Dependent Wind Resource. Energy Conversion and Management, 149, 303–317, 10.1016/j.enconman.2017.07.033.

Jung C. & Schindler D. (2018). 3D Statistical Mapping of Germany's Wind Resource Using WSWS. Energy Conversion and Management, 159, 96–108.10.1016/j.enconman.2017.12.095.

Jung C. & Schindler D. (2019). 'The Role of Air Density in Wind Energy Assessment – A Case Study from Germany'. Energy, 171, 385–392. 10.1016/j.energy.2019.01.041.

Jung C. (2016). High Spatial Resolution Simulation of Annual Wind Energy Yield Using Near-Surface Wind Speed Time Series. Energies, 9, 344. 10.3390/en9050344

Mainzer K., Fath K., McKenna R., Stengel J., Fichtner W. & Schultmann F. (2014). A High-Resolution Determination of the Technical Potential for Residential-Roof-Mounted Photovoltaic Systems in Germany. Solar Energy, 105, 715–731. 10.1016/j.solener.2014.04.015.

Manwell J. F., McGowan J. G. & Rogers A. L. (2009). Wind Energy Explained: Theory, Design and Application. Chichester, John Wiley & Sons. 10.1002/9781119994367.

Najjar, M., Gavrilut, I. and Miocic, J. (2022). RES-TMO Report 2.1.1. Representation of RES Potentials in the Upper Rhine Region. University of Freiburg

Rafique H. (2018) Energy Management in Network Systems. Comprehensive Energy Systems. 5, 581-647. 10.1016/B978-0-12-809597-3.00531-9

RTE (n.d.), Connecting a generating facility [Webpage]. https://www.services-rte.com/en/learn-more-about-our-services/connecting-a-generation-facility.html

Scholl P. & Bär & Karrer Ltd (2020). Electricity Regulation in Switzerland: Overview, Thomas Reuters Practical Law.
https://uk.practicallaw.thomsonreuters.com/Document/Icd17cf50207211e89bf099c0ee06c731/View/FullText.html?transitionType=Default&contextData=(sc.Default)&comp=pluk

Schumacher K., Fichtner W. & Schultmann F. (Eds.) (2017). Innovations for Sustainable Biomass Utilization in the Upper Rhine Region. KIT Scientific Publishing. 10.5445/KSP/1000048433

Swiss Grid (2017). NAV Anhang 2: Allgemeine Bedingungen für den Netzanschluss an das Schweizer Übertragungsnetz (ABNA). https://www.swissgrid.ch/dam/swissgrid/customers/topics/legal-system/grid-connection/netzanschlussvertrag-anhang-2-de.pdf

TRION-climate e.V. (2019). Treibhausemissionen, Energieverbrauch, Erneuerbare: Umsetzung der Klima- und Energieziele am Oberrhein, Kehl.

https://trion-climate.net/fileadmin/Aktivitaeten/Trion_Studien/Energiebericht/Trinationaler_Klima-_und_Energiebericht_TRION_Nov._2019_final.pdf.

Weber C., Tran T. D. B., Elsaesser D., Fritz A., Knapp M., Serradj A., Skupinski G. & Pehle A. (2014). Synthesis Report on Current Resources of Land and Biomass to Produce Bioenergy in the Upper Rhine Region (URR). KITopen. https://publikationen.bibliothek.kit.edu/250099732

Chapter 3:

Capros, P. Vita, A. de, Tasios, N., Siskos, P., Kannavou, M., Petropoulos, A. et al. (2016). EU Reference Scenario 2016 - Energy, transport and GHG emissions -Trends to 2050. Europäische Komission. https://ec.europa.eu/energy/sites/ener/files/documents/20160713%20draft_publication_REF2016_v13.pdf

ENTSO-E (2018): First Edition of the Bidding Zone Review. Final Report. ENTSO-E. Online verfügbar unter https://eepublicdownloads.entsoe.eu/clean-documents/nc-tasks/EBGL/CACM_A32_2018-03_First_Edition_of_the_Bidding_Zone_Review%20(1).pdf.

Heinrichs, H. U. (2014). Analyse der langfristigen Auswirkungen von Elektromobilität auf das deutsche Energiesystem im europäischen Energieverbund. Karlsruhe, Germany: KIT Scientific Publishing

IEA (2016). World Energy Outlook 2016. IEA. https://iea.blob.core.windows.net/assets/680c05c8-1d6e-42ae-b953-68e0420d46d5/WEO2016.pdf.

Keles, D. and Yilmaz, H. Ü. (2020). Decarbonisation through coal phase-out in Germany and Europe — Impact on Emissions, electricity prices and power production. Energy Policy 141, p. 111472. DOI: 10.1016/j.enpol.2020.111472

McKenna, R. (2018). The double-edged sword of decentralized energy autonomy. Energy Policy 113 (3), 747–750. 10.1016/j.enpol.2017.11.033.

NEP (2021): Netzentwicklungsplan Strom 2035, zweiter Entwurf. Hg. v. Übertragungsnetzbetreiber Deutschland. Online verfügbar unter https://www.netzentwicklungsplan.de/de/netzentwicklungsplaene/netzentwicklungsplan-2035-2021.

RES-TMO Report (2.1.1) (2022): Representation of RES Potentials in the Upper Rhine Region. Unter Mitarbeit von Zeina Najjar, Ines Gavrilut und Johannes Miocic. Online verfügbar unter https://www.res-tmo.com/fileadmin/PDFs/Outputs/RES-TMO_Deliverable_2.1.1.pdf.

RES-TMO Report (3.1.1) (2022): Eine geografische Beschreibung des Marktgebietes Oberrhein. Unter Mitarbeit von Joris Dehler-Holland.

RES-TMO Report (3.1.2) (2022): Zwei Szenarien für den Ausbau transnationaler Stromübertragungskapazitäten. Unter Mitarbeit von Joris Dehler-Holland.

RES-TMO Report (3.1.3) (2022): Ein Szenario für den schrittweisen Ausstieg aus verschiedenen konventionellen Technologien. Unter Mitarbeit von Joris Dehler-Holland.

RES-TMO Report (3.2.2) (2022): Ein Modell der Strommärkte in der TMO und den umliegenden Regionen. Unter Mitarbeit von Hasan Ümitcan Yilmaz und Joris Dehler-Holland.

RES-TMO Report (3.2.2) (2022): Ein Modell der Strommärkte in der TMO und den umliegenden Regionen. Unter Mitarbeit von Hasan Ümitcan Yilmaz und Joris Dehler-Holland.

Rosen, J. (2007). The future role of renewable energy sources in European electricity supply. A model-based analysis for the EU-15. Dissertation. Universität Karlsruhe, Karlsruhe. http://digbib.ubka.uni-karlsruhe.de/volltexte/documents/347096

RTE (2019): Le schéma décennal de développement du réseau. Hg. v. RTE. Online verfügbar unter https://www.rte-france.com/analyses-tendances-et-prospectives/le-schema-decennal-de-developpement-du-reseau.

Schumacher K., Fichtner W. & Schultmann F. (2017). Innovations for Sustainable Biomass Utilization in the Upper Rhine Region, KIT Scientific Publishing .doi: https://doi.org/10.5445/KSP/1000048433

Chapter 4:

Canaan B., Colicchio B., Ould Abdeslam, D. (2020). Microgrid Cyber-Security: Review and Challenges toward Resilience, Applied Sciences, 10, 5649. 10.3390/app10165649.

Cyberwatching.eu (2021a) EU Cybersecurity Act | Cyberwatching. Retrieved July 14 , 2021 from https://www.cyberwatching.eu/policy-landscape/cybersecurity/eu-cybersecurity-act

Marron, J., Gopstein, A., Bartol, N. and Feldman, V. (2019) Cybersecurity Framework Smart Grid Profile. National Institute of Standards and Technology Technical Note 2051 National Institute of Standards and Technology. Tech. Note 2051, 142. 10.6028/NIST.TN.2051.

Chapter 5:

Assié A. (2021). Refaire de l'énergie, les épreuves de porteurs de projets “citoyens” dans la production d'électricité. Flux, 126, 26-38. https://doi.org/10.3917/flux1.126.0026

Bafoil F. (2016). Gouvernances, conflits et acceptabilité sociale de l'énergie éolienne: une synthèse comparée, in: Bafoil François (ed.), L'énergie éolienne en Europe. Conflits, démocratie, acceptabilité sociale. Paris, Presses de Sciences Po, 221–251

Baggioni V., Burger C., Cacciari J., Mangold M. (Eds.) (2019). Repenser la transition énergétique. Un défi pour les sciences humaines et sociales. Rennes, Presses Universitaires de Rennes, coll. Espace et territoires, 272 pp.

Bally F. (2015). Vers une transition énergétique citoyenne. La réappropriation des questions environnementales par les acteurs ordinaires. Rives méditerranéennes, 51, 67–79. 10.4000/rives.4940

Bauwens T., Gotchev B., Holstenkamp L. (2016). What Drives the Development of Community Energy in Europe? The Case of Wind Power Cooperatives. Energy Research & Social Science, 13, 136–147. 10.1016/j.erss.2015.12.016

Bourgeois I. (2011). Sortie du nucléaire – quelques pistes de réflexion. Regards sur l'économie allemande, 101, 33–37. 10.4000/rea.4296

Burger C., Weinmann J. (2013). The Decentralised Energy Revolution. Business Strategies for a New Paradigm. Basingstoke, Palgrave Macmillan, 221 pp.

Campos I., Pontes Luz G., Marin-Gonzalez E., Gähr, S., Hall S., Holstenkamp L. (2020). Regulatory Challenges and Opportunities for Collective Renewable Energy Prosumers in the EU. Energy Policy, 138, 10.1016/j.enpol.2019.111212

Cao B. (2015). Environment and Citizenship. Abingdon, New York, Routledge, 308 pp.

Christen G., Hamman P. (2015a). Transition énergétique et inégalités environnementales. Énergies renouvelables et implications citoyennes en Alsace. Strasbourg, Presses Universitaires de Strasbourg, coll. Études alsaciennes et rhénanes , 228 pp.

Christen G., Hamman P. (2015b). Associer les habitants à la transition écologique: Quelle dimension participative des projets d'énergies renouvelables en Alsace?. Cahiers de recherche sociologique, 58, 119–137. 10.7202/1036209ar

Christen G., Hamman P., Jehling M., Wintz M. (Eds.) (2014). Systèmes énergétiques renouvelables en France et en Allemagne. Synergies et divergences. Paris, Éditions Orizons, 331 pp.

Cointe B. (2016). Le tarif d’achat photovoltaïque comme outil d’innovation territoriale : l’exemple des Fermes de Figeac. VertigO, 16, 10.4000/vertigo.17040

Day R. (2021). Energy Justice, in: Coolsaet Brendan (ed.), Environmental Justice. Key Issues. Abingdon, New York, Routledge, 161–175

Depraz S., Cornec U., Grabski-Kieron U. (Eds.) (2015). Acceptation sociale et développement des territoires. Lyon, ENS Éditions, 266 pp.

Evrard A. (2013). Contre vents et marées. Politiques des énergies renouvelables en Europe. Paris, Presses de Sciences Po, coll. Académique, 200 pp.

Foucault M. (1991). Governmentality, in: Burchell Graham, Gordon Colin, Miller Peter (Eds.), The Foucault Effect: Studies in Governmentality. Chicago, University of Chicago Press, 87–104.

Gailing L. & Moss T. (Eds.) (2016). Conceptualising Germany’s Energy Transition. Institutions, Materiality, Power, Space. Basingstoke, Palgrave Macmillan, 147 pp.

Gamberini J. (2016). Villes en transition énergétique : recomposition de l’action urbaine de l’énergie en Allemagne, thèse en urbanisme et aménagement. Université Grenoble-Alpes

Hamman P. (Ed.) (2019). Sustainability Governance and Hierarchy. Abingdon, New York, Routledge, 276 pp.

Hamman P. (2022a). Les coopératives énergétiques citoyennes, paradoxe de la transition énergétique?. Lormont, Le Bord de l’eau, coll. En Anthropocène , 200 pp.

Hamman P. (Ed.) (2022b). Cross-border Renewable Energy Transitions: Lessons from Europe’s Upper Rhine Region (Ed.). Abingdon, New York, Routledge, Routledge Studies in Energy Transitions Series, 266 pp.

Hamman P. & Mangold M. (2020). Les coopératives énergétiques, levier de transition écologique? Quelques réflexions comparées France-Allemagne-Suisse-Belgique. Etopia – Revue d’écologie politique, 14, 136–173. https://etopia.be/revues/

Hamman P. & Vuilleumier S. (Eds.) (2019). Sustainability Research in the Upper Rhine Region. Concepts and Case Studies. Strasbourg, Presses Universitaires de Strasbourg, coll. Études alsaciennes et rhénanes, 346 pp.

Labussière O. & Nadaï A. (Ed.) (2018). Energy Transitions. A Socio-technical Inquiry. Basingstoke, Palgrave Macmillan, 348 pp.

Lestrade B. & Salles A. (2019). La transition énergétique allemande : un pas en avant, deux pas en arrière?. Allemagne d'aujourd'hui, 227, 3-6. 10.3917/all.227.0003

Pellegrini-Masini G. (2020). Wind Power and Public Engagement. Co-operatives and Community Ownership. Abingdon, New York, Routledge, 250 pp.

Pohl N. (2016). Une histoire du temps présent nucléaire: le mouvement anti-nucléaire franco-allemand dans la région du Rhin supérieur, in: Droit Emmanuel, Miard-Delacroix Hélène, Reichherzer Frank (eds.), Penser et pratiquer l’histoire du temps présent. Essais franco-allemands. Villeneuve d’Ascq, Presses Universitaires du Septentrion, 27–36

Ravignan A. (2021). Les énergies renouvelables sont-elles vraiment une catastrophe écologique?. Alternatives Économiques, 416, 60–63. 10.3917/ae.416.0060

Roßmeier A., Weber F., Kühne O. (Eds.) (2018). Wandel und gesellschaftliche Resonanz – Diskurse um Landschaft und Partizipation beim Windkraftausbau, in: Kühne Olaf, Weber Florian (Eds.), Bausteine der Energiewende. Wiesbaden, Springer VS, 653–679

Schumacher K., Krones F., McKenna R., Schultmann F. (2019). Public Acceptance of Renewable Energies and Energy Autonomy: A Comparative Study in the French, German and Swiss Upper Rhine Region. Energy Policy, 126, 315–332. 10.1016/j.enpol.2018.11.032

Chapter 6:

Aras M. (2021a). WP5 Rapport final, Analyse des conditions et des cadres réglementaires pour la coopération transfrontalière en matière de développement des sources d'énergies renouvelables dans la région trinationale du Rhin supérieur. https://res-tmo.com/fr/

Aras M. (2021b). Énergies renouvelables et coopération transfrontalière: la gouvernance multi-niveaux du processus de planification énergétique. VertigO - la revue électronique en sciences de l'environnement. 21 (1). 10.4000/vertigo.31269

Aras M. (2021c). Territorial Governance of EU Cross-Border Renewable Energy Cooperation: A Soluble or Turbulent Model in the Current Framework?. Global Energy Law and Sustainability. 2 (1), 79-97. 10.3366/gels.2021.0048

Aras M., Malfrait L., Hüsch T. (2021). Brochure comparative Regards comparés sur la réglementation des énergies renouvelables dans la région trinationale du Rhin supérieur: clés de lecture pour une coopération régionale renforcée. https://res-tmo.com/fr/

Directive 2009/28/EC. on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives. European Parliament and Council. http://data.europa.eu/eli/dir/2009/28/oj

Hamman P. (Ed.) (2022) Franco-German Cross-Border Cooperation on Hydropower: Regulatory Issues and Future Challenges. Cross-Border Renewable Energy Transitions Lessons from Europe's Upper Rhine Region. Routledge. Energy Transitions Series.

Treaty on the Functioning of the European Union Article 191. Official Journal of the European Union. http://data.europa.eu/eli/treaty/tfeu_2016/art_191/oj

Treaty on the Functioning of the European Union Article 192. Official Journal of the European Union. http://data.europa.eu/eli/treaty/tfeu_2012/art_192/oj

Treaty on the Functioning of the European Union Article 193. Official Journal of the European Union. http://data.europa.eu/eli/treaty/tfeu_2012/art_193/oj

Treaty on the Functioning of the European Union Article 194. Official Journal of the European Union. http://data.europa.eu/eli/treaty/tfeu_2012/art_194/oj

Chapter 7:

Acemoglu, D., Robinson J.A. (2000): Political Losers as a Barrier to Economic Development, The American Economic Review, Vol. 90, No. 2, S. 126 – 130.

Agora Energiewende, IDDRI (2018): Die Energiewende und die französische Transition énergétique bis 2030 – Fokus auf den Stromsektor. Deutsch-französische Wechselwirkungen bei den Entscheidungen zu Kernenergie und Kohleverstromung vor dem Hintergrund des Ausbaus der Erneuerbaren Energien.

https://www.agora-energiewende.de/fileadmin2/Projekte/2017/EW_Deutschland_Frankreich/Agora_IDDRI_French_German_Energy_Transition_2030_Study_DE_WEB.pdf

Alesina, A., Drazen, A. (1991). Why are Stabilizations Delayed? The American Economic Review, 81(5), 1170–1188. http://www.jstor.org/stable/2006912

Bertram, R. Primova, R. (2019). Energieatlas. Daten und Fakten über die Ener-neuerbaren Energien in Europa. Hg. v. Heinrich Böll Foundation.

https://www.boell.de/de/2018/03/20/energieatlas-daten-und-fakten-ueber-die-erneuerba-ren-europa

Bhagwat, P. Keyaerts, Ni, Meeus, L. (2018). Enlarging Incentive Regula-tion to improve Public awareness and Trust in electricity Transmission Infrastrucutre development. Hg. v. European University Institute. Robert Schuman Centre for Advanced Studies.

https://cadmus.eui.eu/bitstream/handle/1814/54884/FSR_Re-port2018.pdf?sequence=4&isAllowed=y

Bössner, S. (2015). Strengthening the European Electricity Market through improved Franco-German Cooperation, Policy Paper 127, Jacques Delors Institute, https://institutdelors.eu/wp-content/uploads/2018/01/franco-germanenergycooperation-boessner-jdi-mar15.pdf

Braun, J F., Roos, H.,Schermers, Bart, V.G, Lucia, Z.C (2019). Dutch-German Energy R&D Cooperations: Practices and Opportunities. Energy R&D Made in Germany: Strategic Lessons for the Netherlangs. Hague Centre for Strategic Studies, 51–66. www.jstor.org/stable/resrep19562.7

Buck, M., Redl, C.,Steigenberger, M., Graichen, P., Agora E. (2016). The power market pentagon. A pragmatic power market design for Europe's energy transition. https://www.agora-energiewende.de/fileadmin/Projekte/2016/Power-Market-Pentagon/Agora_PENTAGON_WEB.pdf

Caferra, R., Colasante, A., Morone, A. (2021). The less you burn, the more we earn: The role of social and political trust in energy-saving behaviour in Europe. Energy Research & Social Science, 71, 1-7.

Caldés, N.,Del Río, P., Lechón, Y.,Gerbeti, A.(2019): Renewable energy cooperation in Europe: What next? Drivers and barriers to the use of cooperation mechanisms. Energies 12 (1), S. 1–22.

Consentec GmbH (2018): Ziele, Anreize und Hemmnisse für den grenzüberschreitenden Ausbau der Stromnetze, Abschlussbericht AP2 für das BMWi, https://www.bmwi.de/Redaktion/DE/Publikationen/Studien/ziele-anreize-und-hemmnisse-fuer-den-grenzueberschreitenden-ausbau-der-stromnetze-ap2.pdf?__blob=publicationFile&v=2

Cousse, J.,Wüstenhagen, R., Schneider, N. (2020). Mixed feelings on wind energy: Affective imagery and local concern driving social acceptance in Switzerland. Energy Research & Social Science, 70, 1-16.

Cuppen, E., Ejderyan, O., Pesch, U. Spruit, S., van de Grift, E., Correljé, A. & Taebi, B. (2020). When controversies cascade: Analysing the dynamics of public engagement and conflict in the Netherlands and Switzerland through "controversy spillover. Energy Research & Social Science, 68, 1-9.

Dermont, C. (2019): Environmental decision-making: The influence of policy information. Environmental Politics, 28(3), 544-567.

Franco-German Council of Ministers (2015). Gemeinsame Energieerklärung, https://www.bmwi.de/Redaktion/DE/Downloads/C-D/deutsch-franzoesischer-ministerrat-gemeinsame-energieerklaerung.pdf?__blob=publicationFile&v=3

DGRV. (2021). Energiegenossenschaften 2021: Jahresumfrage des DGRV. https://www.dgrv.de/news/dgrv-jahresumfrage-energiegenossenschaften/

Drogosch, B. (2018). Bürgerschaftliche Beteiligung an Erneuerbare-Energien-Projekten in Frankreich. DFBEW. https://energie-fr-de.eu/de/systeme-maerkte/nachrichten/leser/buergerschaftliche-beteiligung-an-erneuerbare-energien-projekten-in-frankreich.html

Eichermüller, J. Furlan, M. Habersbrunner, K. Kordic, Z. (2017). Energy cooperatives. Comparative analysis in Eastern Partnership countries and Western Balkans. Hg. v. Z. E.Z. WECF

https://calendar.boell.de/sites/default/files/companalysis_e-coops_eastern_europe_short_version.pdf

Eucken, W., Eucken-Erdsiek, E. (1952): Grundsätze der Wirtschaftspolitik. Bern: Francke.

European Commission (n.d.). Vertragsverletzungsverfahren, https://ec.europa.eu/info/law/law-making-process/applying-eu-law/infringement-procedure_de

Federal Ministry for Economic Affairs and Energy (2020). Bundeswirtschaftsminister Altmaier wirbt bei EU-Konferenz gemeinsam mit den Staaten des Pentalateralen Forums für die Zukunftstechnologie Wasserstoff [Press release]. https://www.bmwk.de/Redaktion/DE/Pressemitteilungen/2020/20200615-bundeswirtschaftsminister-altmaier-wirbt-bei-eu-konferenz-fuer-die-zukunftstechnologie-wasserstoff.html

Feld,L.P.,Fuest,C., Haucap, J.,, Schweitzer, H.,Wieland, V., Wigger, B.U.(2014). Neustart in der Energiepolitik jetzt! Berlin: Stiftung Marktwirtschaft. https://www.stiftung-marktwirtschaft.de/inhalte/publikationen/kronberger-kreis-studien/detailansicht/neustart-in-der-energiepolitik-jetzt/kronberger-kreis-studien/show/Publications/

Fesenfeld, L., Wicki, M., Sun, Y. Bernauer, T. (2020). Policy packaging can make food system transformation feasible. Nature Food, 1, 173-182.

Fesenfeld, L.P., Rinscheid, A. (2020). Emphasizing Urgency of Climate Change No SilverBullet to Increase Policy Support. One Earth, 1- 57.

Franz, K., Goetz, S., Nabholz, M., Raber, W., Zimmer, Y. (2019): Trinationaler Klima- und Energiebericht. Treibhausemissionen, Energieverbrauch, Erneuerbare: Umsetzung der Klima- und

Energieziele am Oberrhein. Hg. v. TRION-climate e.V. https://trion-climate.net/fileadmin/Aktivitaeten/Trion_Studien/Energiebericht/Trinationaler_Klima-_und_Energiebericht_TRION_Nov._2019_final.pdf

Gawel, E., Korte, K. (2014). Das Grünbuch Strommarktdesign: Subventionen für konventionelle Kraftwerke ante portas? WISO Direkt- Analysen und Konzepte zur Wirtschafts-und Sozialpolitik, Dezember 2014, 1-4. https://library.fes.de/pdf-files/wiso/11080.pdf

Gawel, E.. Strunz, S. (2014). State aid dispute on Germany's support for renewables. Is the Commission on the right course?. Journal for European Environmental & Planning Law, 11(2), 137-150.

Gephart, M., Tesnière, L., Klessmann, C. (2015). Driving regional cooperation forward in the 2030 renewable energy framework. Hg. v. Heinrich-Böll-Stiftung. Europäische Union. https://eu.boell.org/sites/default/files/hbfecofys_regional_cooperation.pdf

Goldschmidt, N., Wohlgemuth, M. (2012). Grundtexte zur Freiburger Tradition der Ordnungsökonomik. Tübingen, Mohr Siebeck, 191-222, 315-345

Grasso, M. (2007). A normative ethical framework in climate change. Climatic change 81 (3-4), 223–246. http://www.aari.ru/docs/pub/070316/gra07.pdf

Haas, T. (2019). Struggles in European Union energy politics: A gramscian perspective on power in energy transitions. Energy Research & Social Science, 48 (February 2019) pp. 66-74. Energy Research & Social Science

Hildebrand, J., Renn, O. (2019). Akzeptanz in der Energiewende. Energiewende , 261–282, Springer.

Hilligweg, G. (2018). Grundlagen der deutschen Energiepolitik. Träger - Ziele - Instrumente. Berlin, Münster: LIT (Schriftenreihe des Fachbereichs Wirtschaft der Jade Hochschule Wilhelmshaven, Oldenburg, Elsfleth, Band 8).

Hübner, G., Pohl, J., Warode, J., Gotchev, B., Ohlhorst, D., Krug, M., Salecki, S. & Peters, W. (2020). Akzeptanzfördernde Faktoren erneuerbarer Energien, Bundesamt für Naturschutz BfN-Skripten 551. https://www.bfn.de/fileadmin/BfN/service/Dokumente/skripten/Skript551.pdf

Jacobs, A.M., Matthews, J.S. (2017). Policy Attitudes in Institutional Context: Rules, Uncertainty, and the Mass Politics of Public Investment. American Journal of Political Science, 61(1), 194- 207.

Jacobsen, H.,Klinge; P., Lise L.,Schröder, S., Thorsten; K., L. (2014): Cooperation mechanisms to achieve EU renewable targets. Renewable Energy 63, S. 345–352.

Jobert, A., Laborgne, P. Mimler, S. (2007). Local acceptance of wind energy: Factors of success identified in French and German case studies. Energy policy, 35(5), 2751–2760.

Kahla, F., Holstenkamp, L., Müller, J. R. & Degenhart, H. (2017). Entwicklung und Stand von Bürgerenergiegesellschaften und Energiegenossenschaften in Deutschland. 10.13140/RG.2.2.19726.46407.

Knodt, M. (2019). Steuerung der Energietransformation durch die EU, in: Der moderne Staat. Zeitschrift für Public Policy. Recht und Management, Vol. 12, No. 2, S. 367-381.

Kungl, G. & Geels, F.W. (2018). Sequence and alignment of external pressures in industry destabilisation: Understanding the downfall of incumbent utilities in the German energy transition (1998-2015). Environmental Innovation and Societal Transitions, 26, 78-100.

Kunze, C., Becker, S. (2015): Collective ownership in renewable energy and oppor-tunities for sustainable degrowth. Sustainability Science, 10 (3), 425–437.

Langer, K., Decker, T. & Menrad, K. (2017). Public participation in wind energy projects located in Germany: Which form of participation is the key to acceptance? Renewable energy, 112, 63–73.

Leipprand, A., Flachsland, C. (2018). Regime destabilization in energy transitions: The German debate on the future of coal. Energy Research & Social Science, 40, 190-204.

Leiren, M.D., Reimer, I. (2018). Historical institutionalist perspective on the shift from feed-in tariff towards auctioning in German renewable energy policy. Energy Research & Social Science, 43, 33-40.

Mastropietro, P. (2019). Who should pay to support renewable electricity? Exploring regressive impacts, energy poverty and tariff equity. EnergyResearch & Social Science, 56, 1-8.

Meister, Thomas; Schmid, Benjamin; Seidl, Irmi; Klagge, Britta (2020): How municipalities support energy cooperatives: survey results from Germany and Switzerland. Energy, sustainability and society 10 (1), 18.

Meeus, Leonardo & He, X.. (2014). Guidance to Project Promoters and Regulators on the Cross-border Cost Allocation of Projects of Common Interest, 2014/02, 1-6. https://cadmus.eui.eu/bitstream/handle/1814/29679/PB_2014.02_dig.pdf;jsessionid=ECD9836194D8C40FA57798D51E1B514A?sequence=1

Meeus, L., Keyaerts, N. (2015). First series of cross-border cost allocation decisions for projects of common interest: Main lessons learned, Florence School of Regulation, No. 2015/1, Policy Briefs, Energy, Gas. https://cadmus.eui.eu/bitstream/handle/1814/35017/FSR_PB_2015_01.pdf

Millot, A., Krook-Riekkola, A., Maïzi, N. (2020). Guiding the future to netzero emissions: Lessons from exploring differences between France and Sweden. Energy Policy, 129, 1-13.

Monopolies Commission (2017). Energie 2017: gezielt vorgehen, Stückwerk vermeiden. Sondergutachten der Monopolkommission gemäß § 62 EnWG. 1. Auflage. Baden-Baden: Nomos

Monopolies Commission (2019). Wettbewerb mit neuer Energie Sektorgutachten der Monopolkommission gemäß § 62 EnWG. 7. Sektorgutachten Energie. Bonn.

Munaretto, S., Ward, B. (2019). SIM4NEXUS D2.2. Nexus-relevant policies in the transboundary, national and regional case studies -Main Report-, European Union -Horizon 2020-Societal challenge 5-Climate action, environment, resource Efficiency and raw materials. https://www.pbl.nl/sites/default/files/downloads/Deliverable_2.2_Policy_analysis_case_studies_final-report_2019.02.18.pdf

Neumärker, K. J.B. (2017): Ordnungspolitik, neuer Ordoliberalismus und Mainstream Economics. WISU.(46) 830, S. 830–844.

Next-Kraftwerke (n.d.). What is the energy-only market (EOM)?. Next-Kraftwerk. https://www.next-kraftwerke.com/knowledge/energy-only-market

Nicolli, F. & Vona, F. (2019). Energy market liberalization and renewable energy policies in OECD countries. Energy Policy, 128, 853-867.

Ohlsen, N. (2018). Klimawandelbewusstsein und Akzeptanz erneuerbarer Energien [Universität Bremen].

Ohlhorst, Dörte (2018a). Akteursvielfalt und Bürgerbeteiligung im Kontext der Energiewende in Deutschland: das EEG und seine Reform. In: Lars Holstenkamp und Jörg Radtke (Hg.): Handbuch Energiewende und Partizipation. Wiesbaden: Springer VS (Handbuch), 101–102.

Ohlhorst, Dörte (2018b). Akteursvielfalt und Bürgerbeteiligung im Kontext der Energiewende in Deutschland. Das EEG und seine Reform. In: Lars Holstenkamp und Jörg Radtke (Hg.): Handbuch Energiewende und Partizipation. Wiesbaden: Springer VS (Handbuch), 108–110.

Pahl-Wostl, C. (2009). A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. Global environmental change 19 (3), 354–365.

Poupeau, F.M. (2020). Everything must change in order to stay as it is. The impossible decentralization of the electricity sector in France. Renewable and Sustainable Energy Reviews, 120, 1-11.

Ragwitz, M., Steinhilber, S. and Breitschopf, B., Resch, G., Ortner, A., Busch, S. (2012). RE-Shaping: Shaping an effective and efficient European renewable energy market Authors. Fraunhofer ISI. https://www.researchgate.net/publication/265186295_RE-Shaping_Shaping_an_effective_and_efficient_European_renewable_energy_market_Authors

Resch, G., Held, A., Faber, T., Panzer, C., Toro, F. and Haas, R. (2008). Potentials and Prospects for Renewable Energies at Global Scale. Energy Policy 36(11), pp. 4048-4056. http://dx.doi.org/10.1016/j.enpol.2008.06.029

Rinscheid, A., Pianta, S. & Weber, E.U. (2020). Fast track or Slo-Mo? Public support and temporal preferences for phasing out fossil fuel cars in the United States. Climate Policy, 20, 30-45.

Rivas, J.; Schmid, B.; Seidl, I., (2018). Energiegenossenschaften in der Schweiz: Ergebnisse einer Befragung. WSL Berichte, 71. 108 .

Rodrik, D. (1996). Understanding Economic Policy Reform. Journal of Economic Literature, 34(1), 9-41.

Roland, G. (2000): Transition and economics: politics, markets, and firms, Cambridge, Massachusetts: The MIT Press.

Roland, G. (2002). The Political Economy of Transition. The Journal of Economic Perspectives, 16(1), 29–50. http://www.jstor.org/stable/2696575

Schröder, P.J.H. (2006): Reformverzögerung: Eine Theorie und drei Beispiele. in: T. Eger (Hrsg.), Voraussetzungen für grundlegende institutionelle Reformen, Berlin: Duncker & Humblot, S. 55–72.

Schröder, C., Walk, H. (Hg.) (2014): Genossenschaften und Klimaschutz. Wiesbaden: Springer Fachmedien Wiesbaden.

Schumacher, K., Krones, F., McKenna, R. & Schultmann, F. (2019). Public acceptance of renewable energies and energy autonomy: A comparative study in the French, German and Swiss Upper Rhine region. Energy Policy, 126, 315-332.

Schumacher, K. & Schultmann, F. (2017). Local Acceptance of Biogas Plants: A Comparative Study in the Trinational Upper Rhine Region. Waste and Biomass Valorization, 8, 2393- 2412.

Schulke, Ch. The EU's Major Electricity and Gas Utilities since Market Liberalization. France.

Available at: https://www.ifri.org/sites/default/files/atoms/files/etudesn10cschulke.pdf (Accessed 20 February 2022)

Sebi, C. & Vernay, A. L. (2020). Community renewable energy in France: The state of development and the way forward. Energy policy, 147. 111874. 10.1016/j.enpol.2020.111874.

Schäfer, M. & Keppler, D. (2013). Modelle der technikorientierten Akzeptanzforschung. Discussion paper Nr. 34/2013 12/2013, TU Berlin. https://api-depositonce.tu-berlin.de/server/api/core/bitstreams/e0ae8a09-2125-4d4f-a088-e70c87b3299d/content

Somenergia (2020): Homepage, siehe URL. Online verfügbar unter https://www.somenergia.coop/es/#

Stadelmann-Steffen, I. & Dermont, C. (2021). Acceptance through inclusion? Political and economic participation and the acceptance of local renewable energy projects in Switzerland, Energy Research & Social Science, 71, 1-12.

Strunz, S. (2014): The German energy transition as a regime shift, Ecological Economics, 100, 150-158.

Strunz, S., Gawel, E. & Lehmann, P. (2016). The political economy of renewable energy policies in Germany and the EU. Utilities Policy, 42, 33-41.

Thaler, P. (2020). Energy cooperation between the EU and Switzerland: Partnery by destiny in search of a new model. GovTran Policy. Nr.01: GovTran network, 1-6.

Tobler, C., Beglinger, J. (2020): Tobler/Beglinger-Brevier zum Institutionellen Abkommen Schweiz-EU, S. 1–67.

https://edoc.unibas.ch/78360/1/Tobler-Beglinger-Brevier-Institutionelles-Abkommen_2020-08.1.pdf

Umpfenbach, K., Graf, A., Bausch, C. (2015): Regional cooperation in the context of the new 2030 energy governance. Report commissioned by the European Climate Foundation. Berlin: Ecologic Institute, S. 1–23.

https://www.ecologic.eu/sites/files/publication/2015/regional-cooperation-energy-2030.pdf

UVEK (2017). Linking of the Swiss and European emissions trading systems: big step forward [Press Release]. https://www.uvek.admin.ch/uvek/en/home/detec/media/press-releases.msg-id-67745.html

Uzar, U. (2020). Political economy of renewable energy: Does institutional quality make a difference in renewable energy consumption?. Renewable Energy, 155, 591-603.

Van Baal, P.A. & Finger M. (2019). The Effect of European Integration on Swiss Energy Policy and Governance. Politics and Governance, 7(1), 6-16.

Warren, C. R., Lumsden, C., O'Dowd, S., Birnie, R. V. (2005). 'Green on green': public perceptions of wind power in Scotland and Ireland. Journal of environmental planning and management, 48(6), 853–875.

Weber, D., Hoffrichter, A., Weber, A., Beckers, T., Boldt, B. (2015). Grenzüberschreitende Kooperation beim Zubau von Erneuerbare-Energien-Anlagen in Europa, S. Working Paper, 1–75. https://www.wip.tu-berlin.de/fileadmin/fg280/forschung/publikationen/2015/weber_et_al_2015-grenzueberschreitende_kooperation_beim_ee-zubau_in_europa-v96.pdf

Wierling, A., Schwanitz, V., Zeiß, J., Bout, C., Candelise, C., Gilcrease, W., & Gregg, J. S. (2018). Statistical Evidence on the Role of Energy Cooperatives for the Energy Transition in European Countries. Sustainability, 10(9), [3339]. https://doi.org/10.3390/su10093339

Wüstenhagen, R., Wolsink, M. & Bürer, M. J. (2007). Social acceptance of renewable energy innovation: An introduction to the concept. Energy policy, 35(5), 2683–2691.

Zachmann, G. (2013). Front Matter. In Electricity without borders: a plan to make the internal market work (pp. i–ii). Bruegel. http://www.jstor.org/stable/resrep28599.1

Conclusion:

Bundesamt für Energie – BFE (2020). Schweizerische Statistik der Erneuerbaren Energien 2019, Bern. https://pubdb.bfe.admin.ch/de/publication/download/9765.

Bundesregierung (n.d). Retrieved: June 2022 from https://www.bundesregierung.de/breg-de/themen/klimaschutz/klimaschutzgesetz-2021-1913672 [Webpage]

International Energy Agency (2021a). France 2021 Energy Policy Review. https://iea.blob.core.windows.net/assets/7b3b4b9d-6db3-4dcf-a0a5-a9993d7dd1d6/France2021.pdf

International Energy Agency (2021b). Renewable electricity growth is accelerating faster than ever worldwide, supporting the emergence of the new global energy economy.

https://www.iea.org/news/renewable-electricity-growth-is-accelerating-faster-than-ever-worldwide-supporting-the-emergence-of-the-new-global-energy-economy

Koch B. (Ed.) (2022). Report for the Feasibility Study Innovation Region Fessenheim Upper Rhine. https://www.sustainability-upperrhine.info/fileadmin/documents/FinalReport_Innovation-Region-Fessenheim_preamble-1.pdf