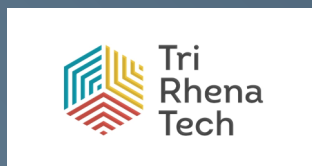




Report for the Feasibility Study

Innovation Region Fessenheim
Barbara Koch (Ed.)



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List of Abbreviations

AEY	Annual Energy Yield
ADEME	Agence de l'Environnement et de la Maîtrise de l'Énergie
AGRO-PV/APV	Agricultural Photovoltaics
ANR	French National Research Agency
BauGB	Baugesetzbuch
BEV	Battery Electric Vehicle
BImSchG	Bundes-Immissionsschutzgesetz
BImSchV	Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes
BMF	Battery Materials Factory
BPI	Banque Publique d'Investissement
BW	Baden-Württemberg
CAM	Cathode-Active Materials
CeA	Collectivité européenne d'Alsace
CGH ₂	Compressed Gaseous Hydrogen
CHP	Combined Heat and Power
CLC	CORINE Land Cover
CO ₂	Carbon Dioxide
CRE	Commission de Régulation de l'Énergie
DF	Dark Fermentation
EDF	Électricité de France (EDF)
EEA	European Environment Agency
EES	Electrical Energy-Storage
EnBW	Energie Baden-Württemberg
EnWG	Energiewirtschaftsgesetz
EoL	End of Life
EPP	Early Pilot Plant
EU	European Union
EV	Electric Vehicle
FeLis	Chair of Remote Sensing and Landscape Information Systems
FhG	Fraunhofer Gesellschaft
GDP	Gross Domestic Product
GDPR	General Data Protection Regulation
GHG	Greenhouse Gases
GIS	Geographical Information System
GM-PV	Ground-Mounted Photovoltaics
GSHP	Ground Source Heat Pump
H ₂	Hydrogen
HFS	Hydrogen Fuel Station
HT	High Temperature
HT Electrolysis	High Temperature Solid State Electrolysers
ICE	Internal Combustion Engines
ICPE	Classified Installation for Environmental Protection
ICPR	International Commission for the Protection of the Rhine
IFES	Integrated Food-Energy System
ISO	International Organisation for Standardisation
KIT	Karlsruhe Institute of Technology
LCA	Life Cycle Assessment

LCIA	Life Cycle Impact Assessment
LH ₂	Liquid Hydrogen
LHV	Lower Heating Value
LIB	Lithium-Ion Battery
LIVE	Laboratoire Image, Ville, Environnement
LNG	Liquid Natural Gas
LOI	Letter of Intent
LPP	Late Pilot Plant
MEC	Microbial Electrolysis Cells
MP	Meteorological potential
NAS battery	Sodium-Sulfur battery
NDA	Non-Disclosure Agreement
NGO	Non-Governmental Organization
NMP	N-Methyl-2-pyrrolidone
NIMBY	Not In My Back Yard
OEM	Original Equipment Manufacturer
OSM	Open Street Maps
P2H/PtH	Power to Hydrogen
PBRM	Perception-Based Regional Mapping
PEM	Polymer Electrolyte Membrane / Proton exchange membrane
PIA	Programme d'Investissements d'Avenir
PV	Photovoltaics
PVDF	Polyvinylidene Fluoride
R&D	Research and Development
RE	Renewable Energy
REP	Registre des Émissions Pollutante
RES	Renewable Energy Systems
RH ₂ INE	Rhine Hydrogen Integration Network of Excellence
SMES	Superconducting Magnetic Energy Storage
SMR	Steam Methane Reforming
SWOT	Strengths, Weaknesses, Opportunities and Threats
TCO	Total Cost of Ownership
TMO	Trinationale Metropolregion Oberrhein
TRL	Technological Readiness Level
URCforSR	Upper Rhine Cluster for Sustainability Research
URG	Upper Rhine Graben
URR	Upper Rhine Region
UVPG	Gesetz über die Umweltverträglichkeitsprüfung
WPD	Wind Power Density
WP2	Working Package 2
WSWS	Wind Speed Wind Shear Model
ZAC	Concerted Development Zone

Executive Summary

The feasibility study Innovation Region Fessenheim presents ideas for innovation pilots in the wider Fessenheim-Colmar-Freiburg region. The focus of the study is on developing a pilot innovation region that aims to attain emission neutrality and sustainability in the energy system based on innovative new technologies and promote local value addition and job creation. Based on a bilateral understanding, the feasibility study will develop a role model for cross-border European regional development. The study proposes ideas for demonstration projects particularly in the fields of "Green Batteries", "Green Hydrogen" and "Smart Grids" and sheds light on the interlinkages and co-benefits of their potential implementation.

The main idea of the feasibility study is to identify viable transformation fields for the innovation region by factoring in the total regional primary energy consumption in order to induce a transformation towards a future-oriented industry and energy market. After analyzing the regional assets of the Upper Rhine and the Fessenheim innovation region and linking them to the postulated goals of the Projet de Territoire, ideas for pilot development that fulfill the requirements of the political requests, highlighted in the Projet de Territoire, were identified. The

ideas for the development of pilots as best practice examples for the region are based on four competence groups in the aforementioned technology fields of "Green Batteries", "Green Hydrogen" and "Smart Grids". The fourth competence group links the pilot ideas from the three technology innovation groups by framing them in a territorial context.

For the acceleration of the regional transformation, the technical innovation pilots, as carriers for this transformation, are described comprehensively in the report along with information on the interlinkages between them, their technical readiness and possible timelines. Moreover, the territorial framework competence group elaborates on the constraints and opportunities in respect to economic rationality, environmental impact, legal aspects, and societal acceptability of the technical innovation ideas. For all technical innovation pilots, a detailed description in the form of pilot sheets is provided in the attachment.

Finally, in the conclusion, a list of next steps for possible activities on political, societal and industrial level is provided.

1. Background and Aim of the Study

The initial impetus of the study originates from the closing down of the nuclear power plant of Fessenheim. The deactivation of the nuclear plant was accompanied by a political commitment from the French and German governments as well as various regional authorities (Projet de Territoire, 2019). The idea was to develop a pilot innovation region towards aiming at emission neutrality and sustainability, based on innovative new technologies for a clean energy system, and while at the same time promoting local value addition and job creation. Based on a bilateral understanding, the feasibility study develops a role model for cross-border European regional development. It aims to advance de-fossilisation by posing key questions of transformation:

- To what extent can we create a regional cross-border energy transformation?
- What are the suitable innovation pilots for the region?
- What are the costs and benefits?
- On which governance and industrial levels do we have to act?

The study proposes ideas for demonstration projects in the fields of “Green Batteries”, “Green Hydrogen” and “Smart Grids” and shows interlinkages and co-benefits of their implementation. Findings build on extensive research on renewable energy system-based, resource-efficient, region-specific energy concepts in the Upper Rhine region (Hamman (Ed.), 2021).

A study by Weichenhein et al. at Roland Berger GmbH (2020), which focuses on Green Hydrogen, highlights the main criteria points (Fig. 1.1) for making the transformation into innovative and climate neutral technology successful.

The conclusions of Roland Berger study (2020) support the idea of the feasibility study: the development of a roadmap, the improvement of competitiveness and the development of pilot projects as best practice examples. Within the overall vision, the report concludes that pushing this transformation forward is of utmost importance. to push the transformation forward.

Pilot projects are interfaces between academia and industry, where scientific knowledge meets practical expertise. Furthermore, when tested in a real-world environment, these pilot project developments offer testbeds for innovations to adapt large scale applications on one side and to trigger further research. This idea of coupling science and industry is fully in compliance with the intentions of the feasibility study.

The feasibility study takes an interdisciplinary and praxis-oriented approach. It aims to work with partners and stakeholders from science, business, politics, administration and civil sectors, to advance the de-fossilisation of the energy system and consequently the economy in the region. The project employs competences within the tri-national platform for sustainability research in the Upper Rhine (URCforSR), individual research institutes (e.g., FhG) and the European Campus (Eucor), which is an overarching coalition of universities. Combining them with the applied expertise of TriRhenaTech, brings together the scientific knowledge and expertise in the Upper Rhine valley from in the fields of technical, economic, legal and socio-cultural sustainability research and innovation. The concepts for sustainability transformation are then further developed with stakeholders from industry and society.



Fig. 1.1: Successful transformation criteria for green Hydrogen as a climate neutral innovation technology (Source: Roland Berger GmbH, 2020:131)

The feasibility study builds upon the priorities expressed in the Projet de Territoire (2019) and the Treaty of Aachen (2019) to enhance cross-border innovation for and de-fossilisation of industrial systems (Fig. 1.2). These goals are embedded in the ambitions expressed by European Green Deal and to provide regions with support for reaching their respective National Determined Contributions (NDCs) as guided by the climate policies.

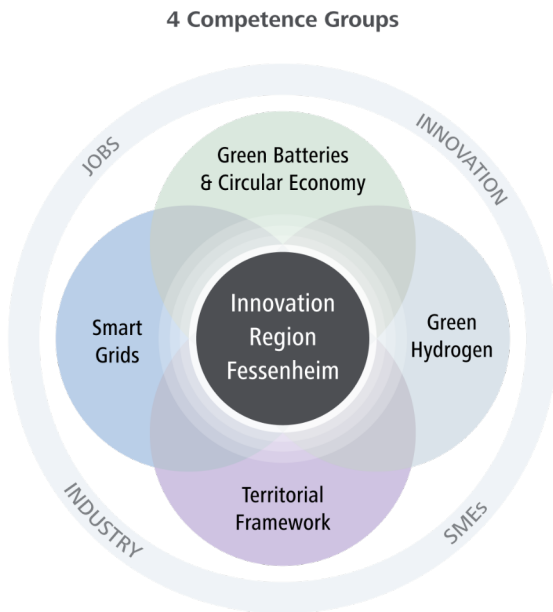


Fig. 1.2: Fields identified for the feasibility study based on the challenges defined in the Projet de Territoire (2019) by communal and regional politicians.

The study works with key stakeholders in four thematic working groups, to provide ideas for pilot/demonstration projects that will aid in the development of key technologies related to which are part of energy transformation pathways. The goal is also to analyze the environmental, economic and regulatory frameworks for the implementation of the pilot projects and derive actions at different governance levels.

As presented in figure 1.2 three technical innovation fields have been established. These innovation fields meet the challenges formulated by the Projet de Territoire for achieving value addition through innovative industries well as to create new jobs through innovation. The three technical innovation fields are complemented by a competence field of analyzing the territorial frame conditions. Based on the identified fields, the following competence groups were established (Fig. 1.3):

- I. Green Battery and Battery Recycling (lead: University of Freiburg and FhG ISE)
- II. Green Hydrogen (lead: KIT)
- III. Smart Grids (lead: University of Haute-Alsace)
- IV. Territorial Framework (lead: University of Strasbourg)

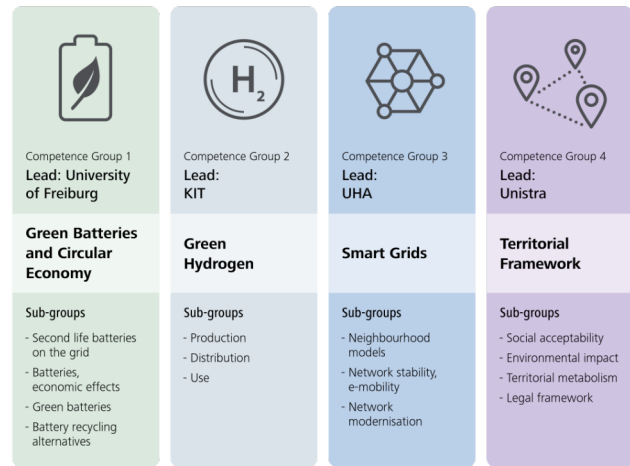


Fig. 1.3: Competence groups for the feasibility study "Innovation Region Fessenheim".

The study was conducted in steady exchange with funding agencies and political members represented in the Strategic Steering Committee. The overall strategic planning was done by a coordination group which monitored the process and was the main link between the experts and the funding organizations (Fig. 1.4).



Fig. 1.4: Governance structure of the feasibility study

The above mentioned fields of innovation are interrelated to each other and the study highlights the idea that transformation towards sustainability needs interlinked thinking. Figure 1.5 illustrates this idea further. The link between batteries and green hydrogen is of great importance for the overall regional transformation, as they are

complementary in terms of implementing a storage system for volatile renewable energy, stabilizing the grid, and contributing to climate neutral transport, and industry processes and applications. Different temporalities of hydrogen and battery storage systems and their different transport applications provide complementary security and flexibility in the energy system. For example, in terms of industrial applications, batteries are agile in their energy supply, but are not adapted to the energy intensive processes, while green hydrogen is efficient and energy saving, especially in energy intensive industrial processes. In terms of transport, batteries could not be completely relied on for passenger traffic, while green hydrogen might outperform batteries in heavy duty transport of ships and trains. In addition, the adaptation of the grid to renewables is necessary for increasing the energy supplied by renewable energy sources and can be supported by the innovative applications described in the battery and green hydrogen innovation hubs, as they can both contribute to a sufficient and timely electricity supply.

By and large, the idea to focus on the above-mentioned fields of innovation has developed out of the need for a holistic approach to transform a region towards sustainability and the analyses of the regional strength in the Upper Rhine. This strength will be described in the following chapter on geographical and regional assets.

The interdependence of the different fields of innovation focused on in this study is visualised in figure 1.5.

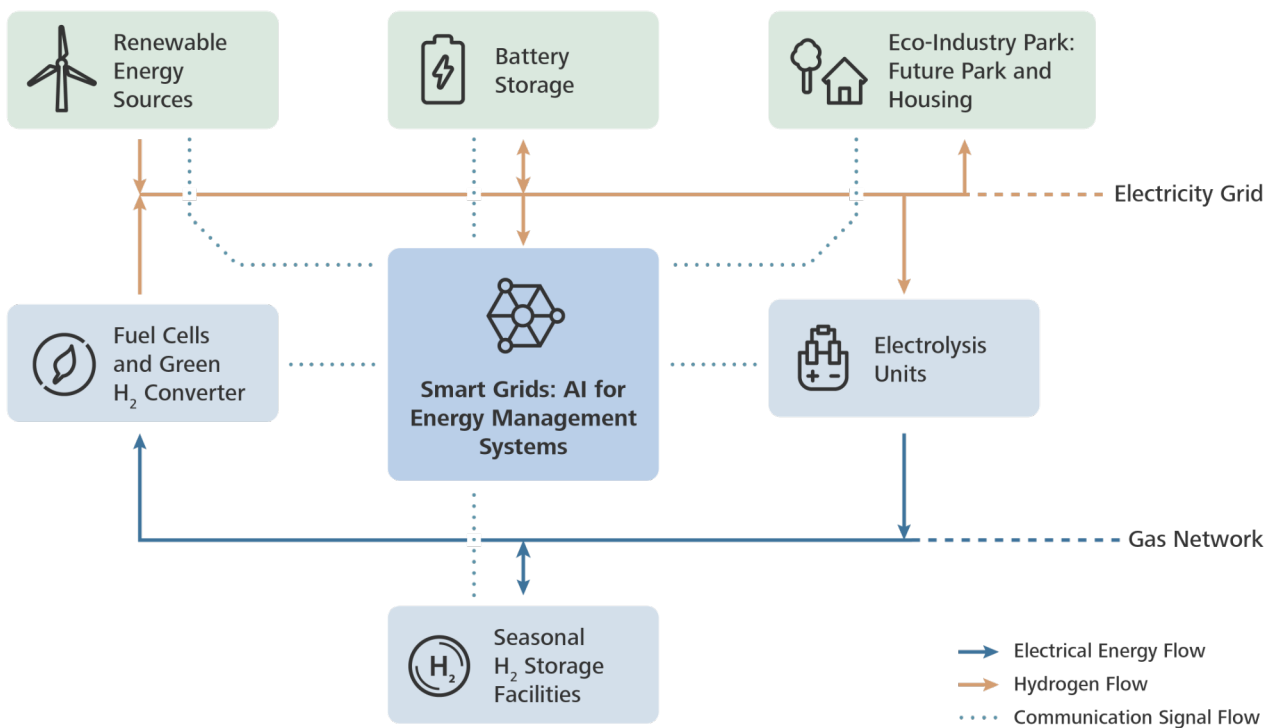


Figure 1.5: Complementarity of energy systems and storage linked by artificial intelligence (AI) Smart Grid management systems

2. Geography and Regional Assets

2.1 Geographical definition of the region

The current geographical framework of the *Projet de Territoire* is defined at three scales. The first perimeter of priority impact addresses the challenges of economic reconversion and includes the commune of Fessenheim and the neighboring communes in the *Communauté de Communes Pays Rhin-Brisach*.

The second perimeter involves the Colmar-Freiburg-Mulhouse triangle (Fig. 2.1), whose operational geographical framework has been defined according to the relations between the neighboring territories on both sides of the Rhine.

Due to the globality of the economic, social and environmental impacts the third scale goes beyond this initial framework and includes the Upper Rhine (Fig. 2.2) along with and the interconnections between the Upper Rhine and the outside world, especially the bordering states and Europe as a whole.

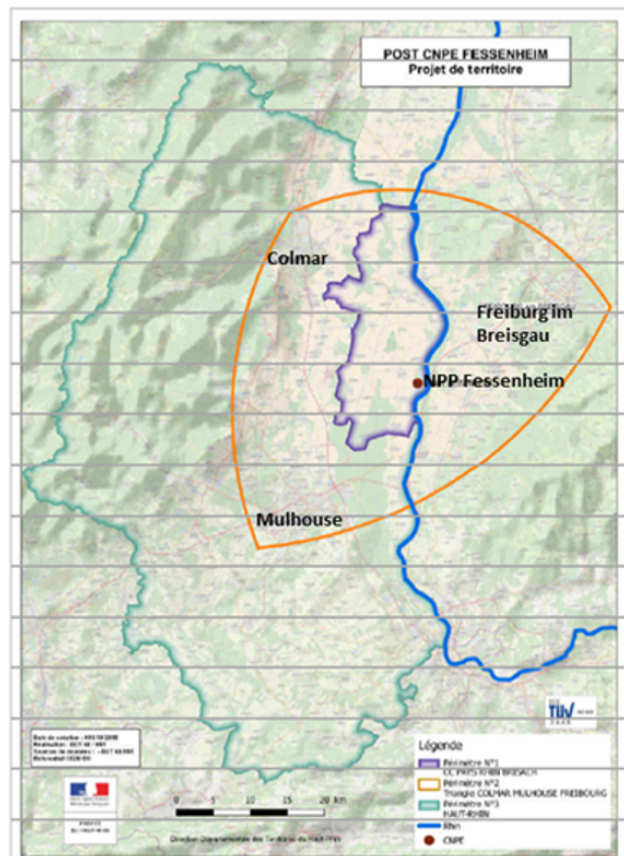


Fig. 2.1: Location of the Innovation Region Fessenheim (*Projet de Territoire*, 2019)



Fig. 2.2: Upper Rhine region (Upper Rhine Conference 2008)

The Innovation Region Fessenheim is located in the Upper Rhine Region at the border triangle of Germany, France and Switzerland (Fig. 2.3). The Upper Rhine Region is dominated by diverse geographies and the Rhine River as the main transport route and natural border. It is characterized by the Rhine valley, enclosed by the mountainous regions of the Vosges in the west and the Black Forest in the east. On the southern edge are the foothills of the Jura in Switzerland. The tri-national metropolitan region has six million inhabitants, strong economic performance and good infrastructure.

The specific geographical and regional characteristics of the Fessenheim region are major assets that enhance its eligibility for above mentioned innovation fields. Further in this chapter, the main considerations for the development of pilots under the aforementioned technological innovation fields are elucidated

2.2. Regional Assets of the Upper Rhine

In the subsequent sections, the significance of Upper Rhine valley is highlighted as its regional assets offer the best conditions for promoting cross-border transformation towards sustainability.

Transport Infrastructure

The natural geographical and political conditions have led to a concentration of energy-intensive industries along the Rhine. They have favored a strong north-south split of transport and supply lines, while east-west connections are concentrated on a few bridges across the Rhine. The Upper Rhine valley is one of the most important European transport corridors connecting the leading European sea harbors Rotterdam – Genoa – Marseille (Fig. 2.3). There exists a network of major train railways from north to south, the highway infrastructure that runs along the Upper Rhine through the alpine areas and there are shipping routes of the Rhine and the Rhone. Therefore, the Upper Rhine allows for multimodal and efficient transport of goods, given the importance of the transport of heavy goods through vessels. Also, the numerous harbors along the Upper Rhine provide excellent conditions for port loading and unloading (Deutsch-französisch-schweizerische Oberrheinkonferenz, 2014).



Fig. 2.3: The Upper Rhine region within European transport corridors (edited from European Commission 2020: TEN-T Core Network Corridors).

Besides the European transport corridors in the Upper Rhine valley, important European gas pipelines and power lines are also located within the area. These are facilities which can be used to transport green electricity or green hydrogen in the future (Fig. 2.4). Pipelines for transporting natural gas and green hydrogen can be adapted to allow for different usage of existing infrastructure.

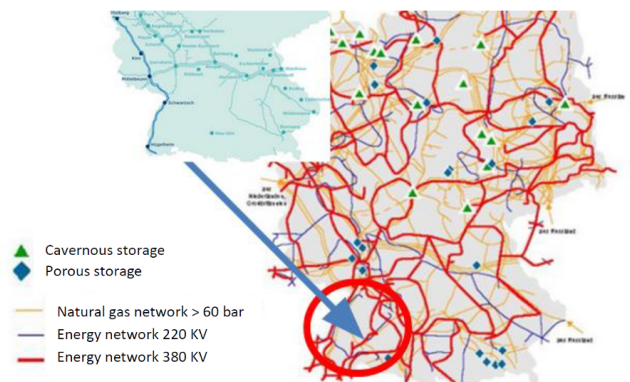


Fig. 2.4: European electricity power lines (red) and gas pipelines (yellow) (BHKW jetzt, n.d.).

Legal frame

The Innovation Region Fessenheim is one of the priority projects defined by the Treaty of Aachen (2019). In Chapter 4, Article 13 - 17 and in Chapter 5 Article 18 – 22, the commitment to regional transnational cooperation and to sustainable development is clearly expressed. Activities of France and Germany are bound to “constitutional rules of the two states and within the framework of European Union law” (Ibid. 2019). The Aachen Treaty further states to “provide local authorities of border regions as well as cross-border entities such as Euro districts with adequate competences, dedicated resources and accelerated procedures”. This is to make sure that obstacles involved with the implementation of cross-border projects are overcome, particularly in the economic, social, environmental, health, energy and transport fields. If no other instrument enables them to overcome such obstacles, adapted laws, regulations and administrative provisions, including derogations, may also be provided for. In this case, it is for both States to introduce relevant legislation” (Ibid. Article 13, §2).

The legal frame of the Aachen Treaty and the derived priority projects identified under the treaty, provide the best conditions for the development of innovative ideas and projects designed in this feasibility study. The objectives defined in the Treaty of Aachen and the highlighted priority projects are fully compliant with the goals and innovation pilots of the feasibility study.

Economy

The Upper Rhine is an area with high economic potential. It has a GDP of €272 billion/year, which is more than that of Finland and Ireland combined (Regierungspräsidium Freiburg 2020, n.d.). In addition to the relatively high number of big industries that push for development, there are several small and medium enterprises that may contribute effectively (Interreg Upper Rhine, 2019). Chemical and pharmaceutical industries, some of which are signifi-

cant global players, play a key role in employment and value creation (Fig. 2.5). Vehicle manufacturing and other production industries are equivalently important and have a strong impact on production chains (e.g., metal construction and engineering).

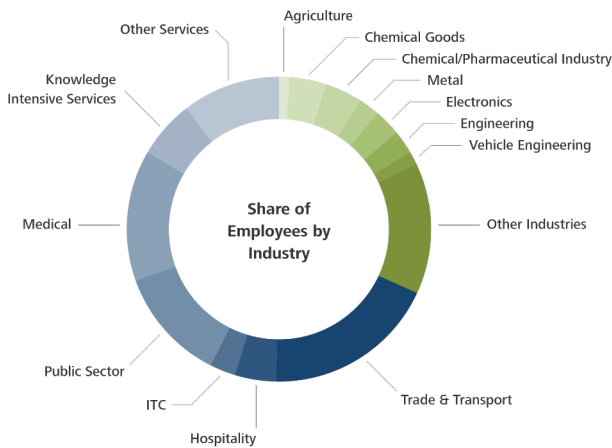


Fig. 2.5: Employee shares according to economic branches in the Upper Rhine Valley (Regio Basiliensis, 2021)

Annual growth rates (2010-2018) in the Upper Rhine region correspond to the German and Swiss national average. They are significantly lower in Alsace compared to the rest of France and lag behind other border regions (e.g., South Palatinate) (Fig. 2.6). Innovative potential from a growing science sector (Regio Basiliensis, 2020) has not yet paid out. To keep and accelerate the green economic growth in the Upper Rhine region, technology transfer towards enterprises must be increased. The EU study on "Quantification of the Effects of Legal and Administrative Border Obstacles in Land Border Regions" (EC, 2017) shows that better economic, administrative and legal interconnections in the EU member states could boost growth by €485 billion and create 8 million new jobs in border regions.

Real GDP Growth 2010-2018

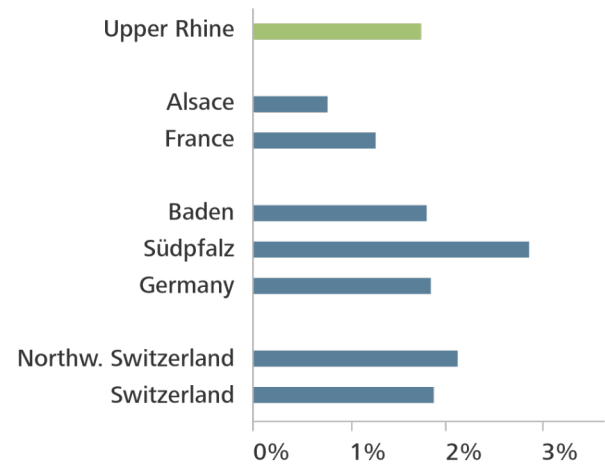


Fig. 2.6: The economic growth of the Upper Rhine region during the years 2010 to 2018 (Regio Basiliensis, 2021).

The global competitiveness of the energy intensive, high wage industries in the region will depend on their innovative capability and more efficient resource use (Zuoza and Pilinkiene, 2021). The Upper Rhine must not lose out in the energy and circular economy sector. The connection to the European value chains as described in the European Commission communication "New Industrial Strategy of Europe" (COM, 2020 102 final) is of great importance for the region and for the strategic autonomy of Europe as a whole. With the importance of traffic and trade in the Upper Rhine, climate neutrality heavily relies on reductions in the transport sector. The active involvement of automotive companies like Stellantis and Daimler is deemed inevitable for the feasibility of a green transition. Pilots in this study are chosen to enable economic co-benefits between sectors. For instance, green transformation is thought to make tourism more attractive.

Science Capacity and Education

The Upper Rhine is home to a high density of research and education organizations (Fig. 2.7). Internationally renowned companies and organizations in the fields of energy, technology and sustainability, along-with in addition to universities and private enterprises, create a vast network for innovation. Additionally, there is vast experience in tri-national cooperation and cross-border competence, shared among the various regional players in sub-regional networks such as Eucor - The European Campus and TriRhenaTech and the Upper Rhine Cluster for Sustainability Research (URCforSR). Projects on regional transformation in competence fields such as "Green Hydrogen", "Green Batteries" and "Smart Grids" benefit from the strong coalition of basic and applied science.

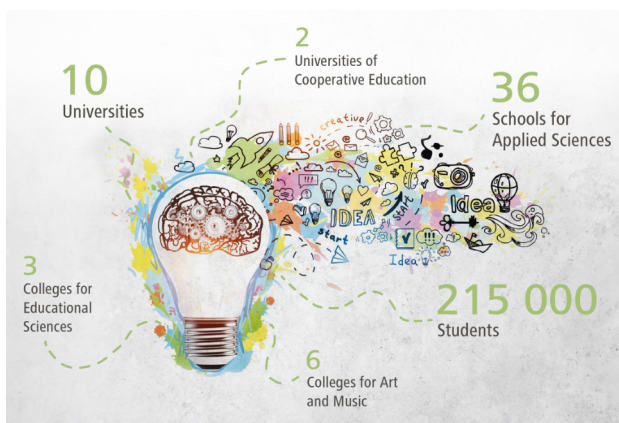


Fig. 2.7: Overview of the science research competences in the Upper Rhine (Trifob n.d.)

Human resources

There is a high concentration of human resources, especially among young students and workers in the Upper Rhine. This is amongst others, due to an exceptional education infrastructure and attractive job opportunities. Mobility and interdisciplinary exchange also play a significant role. The Eucor Universities with 117.000 students in total (Eucor, 2022) already provide 15 cross border programs. TriRehnaTech offers a number of tri-national studies, especially in engineering sciences. Applied projects support local competences, influence the design of new courses and create valuable knowledge on the Upper Rhine sustainability transformation. With a yearly release of approximately more the 2000 graduates from the EUCOR universities only, there is a considerable potential for human resources.

Transnationality

The Upper Rhine valley is located in the triangle of Switzerland, France and Germany. Along the common borders of the three nations there exists intensive exchange between administrative, scientific and economic organizations. Overcoming administrative and legal barriers, providing regional expertise that transcend national borders, and accelerating knowledge transfer between companies, societies and science organizations is an asset which privileges border regions in general. This has been confirmed by the report from the European Commission study on the quantification of cross border effects (EC, 2017), and the Upper Rhine Valley specifically, due to the long common past of cross-border activities. Cross-border hubs increase cross-border flexibility for employees and multiply the resources for joint investments. Likewise, cross-border hubs advance intercultural understanding, joint political visions, and strengthen Europe's position in the world.

2.3. Local assets of the communities within the innovation region Fessenheim

In this section, the more specific assets of the innovation region Fessenheim are described, which are embedded in the Upper Rhine overall significance benefits.

2.3.1. Fessenheim

Fessenheim (Alsatian: Fässene) is a French community in the Haut-Rhin Department within the Grand Est region with a population of approximately 2300. It is located about 25 km northeast of Mulhouse on the Rhine canal and thus is close to the German border. Southeast of the village center is France's oldest nuclear power plant, the Centrale Nucléaire de Fessenheim operated by Électricité de France (EDF). From 1978 to 2020, two pressurized water reactors were in service, each with a net electricity output of 880 MW. With 2000 people working at this station, it was a major employer in the region (EDF, 2019).

Fessenheim connects to the neighboring areas through the D52 motorway on the French side and the Alain-Foechterle-Erich-Dilger Bridge to the German side. The single-lane bridge, opened in 2006, links to Junction 64b of the Federal German Motorway 5. From here, the twin municipalities of Hartheim and the towns of Grißheim and Heitersheim are within reach. The international EuroAirport Basel-Mulhouse-Freiburg and other small airports are located nearby.

2.3.2 Nambenheim / EcoRhena

New industries are expected to settle in the vicinity of Nambenheim as part of the EcoRhena Project (Projet de Territoire, 2019). Located close to the Fessenheim area, the project EcoRhena aims to attract new companies by offering them a large and flexible area; furthermore, it intends to develop a business park on the banks of the Grand Canal d'Alsace. With Hartheim on the opposite side of the Rhine, Nambenheim faces a strong industrial counter-area. The surface area for the business park was estimated at 220 hectares but reduced to 82 hectares for environmental constraints (Conseil Départemental du Haut-Rhin and Conseil Départemental du Bas-Rhin, 2019). The development project of this park and the creation of the concerted development zone (ZAC), initiated by the officials of the Communauté de Communes Pays Rhin Brisach and the municipalities of Balgau, Nambenheim, Heiteren and Geiswasser, are among the "Plans d'Avenir" alternative measures to address and overcome the closure of the Fessenheim power plant (Préfecture du Haut-Rhin, 2021).

This area offers several advantages, such as privileged geographic border location, river transport infrastructures, tax reductions, job creation subsidies, environmental richness of the territory. However, despite the dedicated commitment to sustainable development through encouragement for setting up international and local companies, considering EcoRhena as a zone for hosting the intended pilot projects seems challenging. Today the schedule for its commercialization does not correspond very well with the feasibility study specification. This is due to the complicated nature protection concerns, which must be duly considered. A faster implementation might be possible with a test innovation park, for convincing local citizens and investors, if the process for the innovation park Fessenheim yankees time to speed up.

3. Renewable Energy Potentials in the Upper Rhine Region

The transformation towards sustainability is connected with the transformation to clean green energy. In fact, the European Parliament defines renewable sources of energy as: wind power, solar power, hydroelectric power, ocean energy, geothermal energy, biomass and biofuels. Latest discussions in the European Commission also propose nuclear energy under certain conditions and within a limited time frame as green energy. However, this view is not shared by all member states, and especially not by Germany. In this report we define the term green energy using the stricter definition that was used before 2022 and described in the Renewable Energy Directive. Green energy sources reduce GHG emissions and are better alternatives for energy production than fossil fuels. In July 2021, the European Commission proposed increasing the proportion of renewable energy in the EU energy mix as part of its binding targets in the Renewable Energy Directive and the promotion of renewable fuels such as hydrogen (European Parliament, n.d.). In a study carried out within the Interreg Upper Rhine project, named Regionale Konzepte für eine integrierte, effiziente und nachhaltige Energieversorgung und Speicherung in der Trinationalen Metropolregion Oberrhein (RES-TMO), the technical potentials for renewable energy generation in the Upper Rhine Region were investigated. The results are briefly presented in this chapter. For a better understanding of the results, it is important to define the different types of potentials for renewable energy generation and to explain the methodology, i.e., how the results have been reached.

The following chapter is based on the outcome of the RES-TMO project and taken from the report titled "Representation of RES Potentials in the Upper Rhine Region" by Najjar et. al. (2022). The methodology is only briefly presented in this section as further explanations can be found in the original report.

3.1 Methodology and results of the potential studies on renewable energy production

It is possible to study different categories of potentials; therefore, it is important to clearly define the different levels before analyzing the renewable energy potential. As presented in the table below, the different potential levels are: theoretical, geographical, technical, economic and feasible. The complexity of the potential output increases incrementally with each potential level as more and more criteria are included. Mc. Kenna et al. (2021) presented the different potential analysis levels for wind energy. The different categories are also valid for other renewable energy studies. In the table below, the potential levels for renewable energy studies are defined and are additionally classified according to their political relevance (Tab. 3.1).

Potential term	Definition	Policy relevance
Theoretical or physical potential	Total energy content of wind, e.g., globally	Generally irrelevant
Geographical potential	The geographical area available for wind turbines, e.g., globally	Generally irrelevant
Technical potential	Electricity that can be generated from wind turbines within the geographical potential, over a given period of time (e.g. a long-term average on an hourly time series over a specific year), and with a given turbine technology (e.g., current, future)	Wind industry R&D, innovation and market dynamics
Economic potential	Subset of the technical potential that can be realized economically	Energy-political frameworks
Feasible potential	Subset of the economic potential after accounting for non-technical and non-economic constraints	Public acceptance, market barriers, inertia / resistance

Tab. 3.1: The different potential study categories (McKenna et. al, 2021)

The results presented in RES-TMO are based on the study of the theoretical, geographical and technical potential, and the final results depict the technical potential which according to McKenna et al. (2021) is of high political relevance for starting innovations and understanding this report's innovation programs and pilots. The economic potential and the feasible potential were not taken into consideration, because they are strongly influenced by concrete market measures and pilot implementation in defined locations. For the Upper Rhine Region, the potentials have been studied on the technical potential level so far.

Based on the definition by Jäger et al. (2016), the technical potential takes into account technical constraints limiting the theoretical energy yield like conversion efficiencies of PV modules and wind turbines. 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 (turbulence and reduced wind speed) determine the technical wind energy potential. The technical PV energy output is-among others- influenced by the reflectivity of the PV module itself, which is related to the solar angle of incidence, the PV module temperature that is depending on the surrounding temperature and the prevalent surface wind speed (Huld, 2017).

The study conducted for RES-TMO started with an expert opinion investigation by interviewing experts in France, Switzerland and Germany to better understand the major regulatory and process barriers for the RES production infrastructure implementation and to take them into consideration as much as possible in the frame of accessible data. 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 by definition the geographical potential. The geographical potential by definition 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 residential or protected 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 types of potential that require different land-use area types: conventional GM-PV and 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.

In Switzerland, there are stringent regulations and no clear guidelines when it comes to wind energy and 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 favorable. 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. However, an adaptation is needed for distinct pilot projects.

The report also includes an analysis of the land use, topography and meteorological conditions for each investigated RES in order to help estimate the technical potential in a credible way. In the following paragraphs, a short description of the methodology divided by RES and developed by WP2 of the RES-TMO project is presented.

3.1.1 Wind

The mountainous terrain and orographic complexity of the study area requires a high-resolution grid and a high temporal resolution in order to capture the small-scale features of the wind distribution, a process that needs enormous computational resources. Therefore, the wind energy potential is based on data from the wind speed wind shear model (WSWS) developed and described by Jung & Schindler (2017) with an 250m x 250m. Using this information, conclusions about the geographical variations of the wind energy potential in the Upper Rhine Region was possible. The model provides reasonable results for long-term annual and monthly averages of wind speed.

In the calculations of wind potential, Grau et al. (2017) aptly and descriptively name the broadest potential category (the theoretical potential), the meteorological potential (MP), because it depicts the “available kinetic energy contained in the atmosphere over an area” which can be assessed by the wind power density (WPD in W/m^2). Therefore, the first step of calculating the MP requires the calculation of the WPD which is mathematically related to the wind speed. The yearly and monthly median wind speeds were extrapolated to three chosen hub heights at 120m, 140m and 160m by using the Hellmann power law. The WPD at the level of the three chosen turbines was calculated by using the wind speed values. Based on Manwell et al. (2009), potential wind turbine sites can then be classified according to the available wind power density into three categories:

- $WPD < 100 W/m^2$ is considered inappropriate
- $WPD \approx 400 W/m^2$ is considered as appropriate
- $WPD > 700W/m^2$ defines regions of great wind power resources

By classifying the study area according to the three WPD categories described above, the meteorologically suitable areas are found.

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

Finally, the technical potential is calculated. The technical potential minimizes 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) (Grau et al., 2017). In the literature, Jung (2016) describes in detail the steps to calculate the Annual Energy Yield (AEY) estimation by using power curves.

The GIS raster files used for the calculations are taken from the raster files developed for the Master’s thesis, Wind Energy Assessment in the Upper Rhine Region submitted in 2020 by Michael Chimeremeze Ezem. The author used the measurements of 64 weather stations, divided over the three countries, for surface wind speed to calculate the meteorological potential in the study area based on the wind speed wind shear model (WSWS) developed and described by Jung & Schindler (2017).

The results of the method described above are presented below Fig. 3.1 and 3.2.

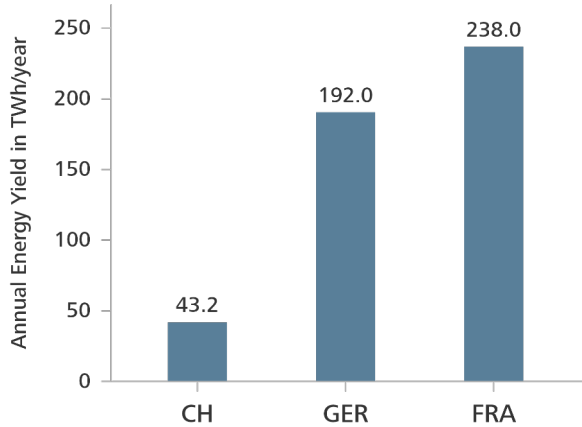


Fig. 3.1: Preliminary wind technical energy potential in TWh per year by country in the Upper Rhine

Previous Wind Energy Potential	473	473
Wind Potential Reduction Factor	27	%
New Wind Energy Potential	128	TWh

Tab. 3.2 Wind Energy Potential after corrections and refinement by Najjar et al. (2022)

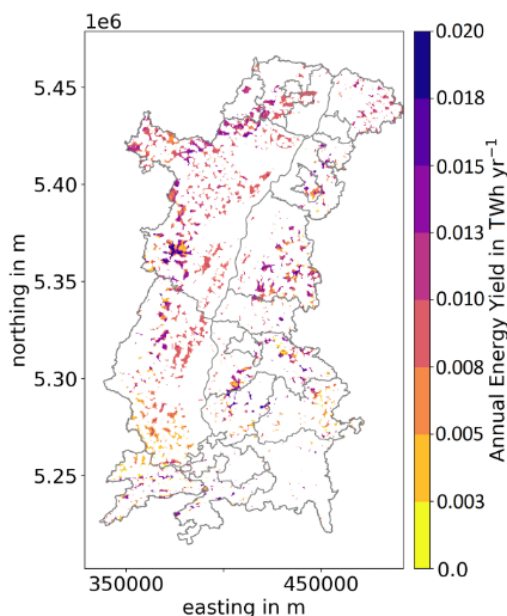


Fig. 3.2: Distribution of technical potential for wind energy on the usable area in the Upper Rhine in TWh per year (Najjar et al., 2022, 21)

The results show that the technical potential for wind energy production in the Upper Rhine Region is relatively high in France and Germany. Taking into consideration that for the whole Upper Rhine Region according to statistical assessment as calculated from the energy use per capita in 2016 for Grand Est, Basel department and City as well as Baden-Württemberg (Tri-National Climate and Energy Report, TRION-climate 2019/27) the total energy demand per year in the Upper Rhine Area is approximately 212,41 TWh per year as per the calculations in the table 3.3 below.

URR	Population in 2019	Final Energy demand in 2016 in MWh /capita	Energy demand in URR in MWh/yr	Energy demand in URR in TWh/yr
CH	1.507.718	49	73.878.182	73,88
GER	2.858.606	26	74.323.756	74,32
FR	1.888.480	34	64.208.320	64,21
Total	6.254.804		212.410.258	212,41

Tab.3.3: Energy demand in the URR in TWh/yr (Sources: *Eurostat (n.d.) ** Tri-National Climate and Energy Report, TRION-climate 2019/27 *** calculated)

If all the technical potential had been used, more than 50% of the final energy demand in 2016 could have been covered by wind energy. However, it is clear that only a smaller percentage of the technical potential can be implemented because it depends on the economic and regulative conditions as well as societal acceptance. The economic and feasible potential take the aforementioned elements into account but as stated earlier will require a case-to-case analysis.

3.1.2 Solar PV

The investigation of the solar energy potential in the Upper Rhine was divided into two categories: roof-top PV and free-range PV installations that was also divided into two sub-categories ground-mounted GM-PV and AGRO-PV as described in the sections below.

a) Rooftop Potential

The possibility of placing PV panels on building roofs (PV rooftop potential) offers a large potential for electricity production. Compared to the free-land PV energy potential, the rooftop potential does not evoke land use conflicts and only to a small degree conflicts with monument protection issues, resulting in a higher public acceptance (Mainzer et al., 2017).

For the theoretical energy potential, the software package PVMAPS was used to calculate the solar irradiation. PVMAPS takes 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 generated rasters depict average yearly global irradiation in Wh/m^2 received by the URR and can be calculated based on the inclination angle of the solar panels and their orientation. The choice of orientation and inclination angles was determined by assumptions related to the geographical potential and are discussed below.

The geographical potential consists of roof areas, so buildings in the URR were extracted from Open Street Maps (OSM), clustered, and mapped; consequently, an estimation of the ground area of buildings and number of buildings per municipality was obtained. It was important for buildings to be clustered together because taking individual buildings into account results in large files that often lead to problems and computational errors. It was assumed that the ground area of the buildings is equal to the roof area. Mainzer et al. (2014) developed a method for solar PV rooftop potential calculation and used it to perform a high-resolution estimation of the residential rooftop PV potential in Germany. The method used here to calculate the geographical and technical potential is based on the one used by Mainzer et al. (2014).

All possible combinations of orientation and inclination are considered together and are generated by using the PVMAPS package resulting in different maps depicting solar irradiation. Applying the generated solar irradiation maps to the available roof area (usable area in this case) results in the geographical potential of rooftop PV in the URR. The last step of the geographical potential is factoring in the roof utilisation factor, which accounts for the "share of the roof area that may be used for PV installations, due to constructional constraints like chimneys, ventilation systems, antennas etc." (Mainzer et al, 2014, p. 719). The roof utilisation factor has been estimated by many previous studies. Mainzer et al. (2014) propose that this factor be considered 58 % for slanted roofs. In comparison to those from previously conducted studies, it is a larger than average number because no orientation direction is excluded.

The final step is the calculation of the technical potential which can be achieved by factoring in the technical parameters of the polycrystalline silicon solar cell installations, the most used type so far, such as average module efficiency (14.5%) and the performance ratio (85%). The out-

put of this stage is the energy produced (in Wh/year) by the rooftop PV panels (Mainzer et al., 2014).

The results are presented in the figures below. It has to be highlighted that the rooftop calculations do not factor in any monument restrictions due to the clustering method used for buildings.

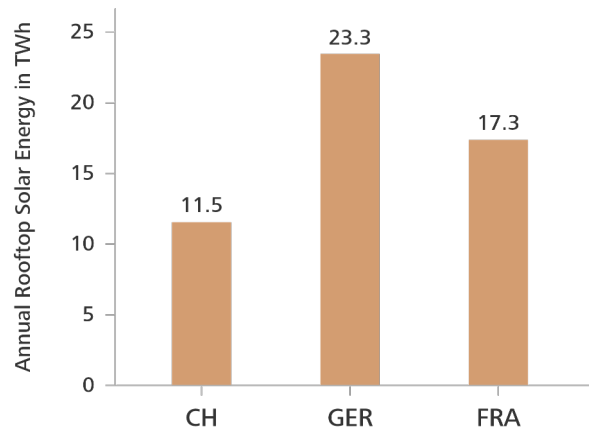


Fig. 3.3: Rooftop Solar PV potential in the Upper Rhine Region in TWh/y (Najjar et al., 2022, 22).

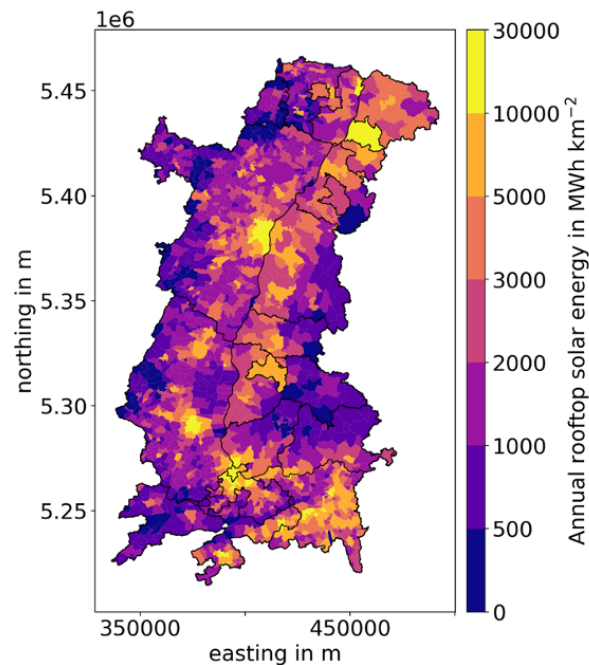


Fig. 3.4: Distribution of the rooftop PV potential per municipality in the Upper Rhine Region (Najjar et al., 2022, 23).

If the technical potential of rooftops is fully usable then approximately 24% of the total energy use from 2016 will be covered. However, as shown previously, the total technical potential is not usable due to restrictions like load capacity of roofs, shadowed roofs and monumental restrictions as well as the preparedness of citizens to invest in the installations. If 40% to 50% of roofs covered by solar panels can be reached in the long run this would be a strong success and is only achievable under best frame conditions. The societal acceptance for this renewable energy source is relatively high (Cousse, 2021).

b) Ground-/ AGRO-PV Installations

Ground-PV installations are considered one of the most competitive sources for energy production worldwide and the demand for it is continuously increasing regardless of the decreasing availability of land, especially in Europe, or its lower acceptability compared to rooftop-PV (Cousse, 2021). In order to avoid future economic, social, ecological and political conflicts, one of the proposed solutions for the land-use conflict and competition evoked by ground-PV is to resort it to the Integrated Food-Energy System (IFES) which allows for a simultaneous production of energy and food through agro-photovoltaic systems (APV). France has already implemented APV dissemination policies and these policies are in discussion in Germany. Since 2015 in Germany, crop-land used for GM-PV is no longer considered eligible for the subsidies awarded by the common agricultural policy of the European Union because it is considered as an expansion of built-up area. Schindele et al. (2020) proposes that in the general discussion of land-management, the land used for GM-PV dissemination should be considered as expansion of built-up area and therefore should not include arable land with certain agricultural practises, which in turn should be explicitly related to APV as it may even improve the agricultural yield according to some studies and observations.

For the assessment of the potential free-range PV installations, the land use data sets offered by Copernicus land monitoring services, specifically the CORINE land cover (CLC) data from 2018 was used. The land cover dataset was taken from the Copernicus website¹. This land-cover dataset includes around 44 layers representing different land-cover and land-use classes. A published guide, Updated CLC Illustrated Nomenclature Guidelines, also thoroughly describes the components of the different layers. In the calculations for free range-PV potential, at the geographical potential level, after the exclusion of the restricted areas, the usable land was further divided into two categories:

- a) Arable land which includes non-irrigated arable land, vineyards, fruit tree and berry plantations. For further details we refer to EEA et al. 2019. This category depicts arable land where agricultural activities take place and by definition was assumed to be the usable land for AGRO-PV installations.
- b) Arable land which includes the following class pastures respectively permanent grassland. For further details please refer to EEA et al. 2019. This category depicts the arable land - pastures - used for animal husbandry activities and which by definition was assumed to be the usable land for GM-PV installations.

CLC maps were also used to determine the restricted areas, in addition to the restricted area guidelines taken from the criteria catalogue of Baden Württemberg. Some layers were evaluated as inappropriate for PV dissemination by studying their description.

For calculating the theoretical potential of APV & GM-PV as defined above, PVMAPS package was again used; however, in this case, the orientation and inclination angle could be optimised because they are not constrained by the architecture of already existing structures like the solar rooftop PV potential is. The geographical potential was then calculated in two steps: the first step was to include the restrictions found in the criteria catalogue from Baden Württemberg and the CLC land cover areas that are unsuitable. The second step was to separate the usable area depending on the type of land: agricultural activity area or pastures so that the potential could be divided at this stage between GM-PV and AGRO-PV. 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.

The figures below depict the results (3.5 and 3.6) for GM-PV (free-range PV on pastures) and AGRO-PV (free-range PV on land where agricultural activities take place). In addition, in Fig. 3.7 and 3.8 the spatial distribution of the technical potential of free-range PV (as divided between GM-PV and AGRO-PV) is presented. Considered to be beyond the scope of the study is the technical potential of floating PV.

¹ <https://land.copernicus.eu/pan-european/corine-land-cover>

GM-PV Potential per Country

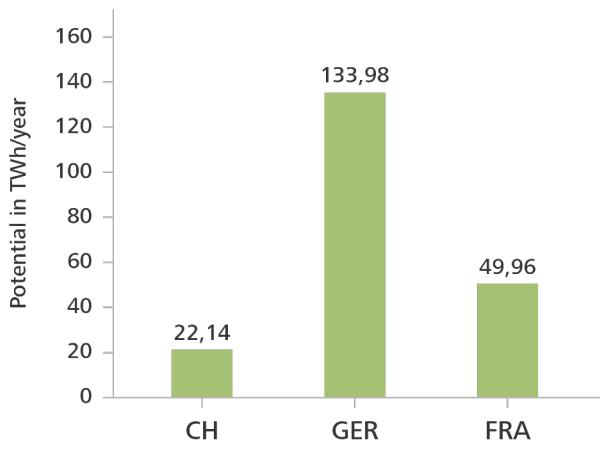


Fig. 3.5: Preliminary technical potential of GM-PV in the Upper Rhine Region (Najjar et al., 2022, 24).

Yearly Ground Mounted-PV (GM-PV) Potential in the URR

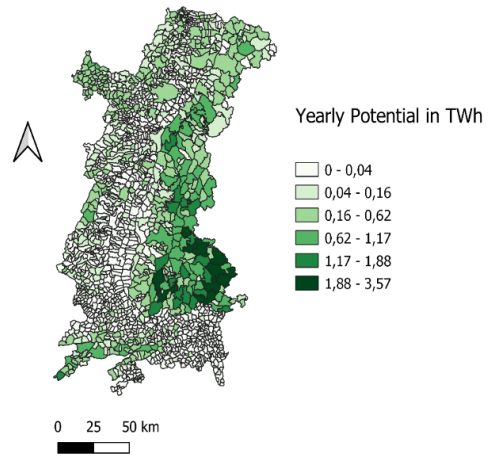


Fig. 3.7: The technical potential of GM-PV per municipality of the Upper Rhine Region (Najjar et al., 2022, 24).

Agro-PV Potential per Country

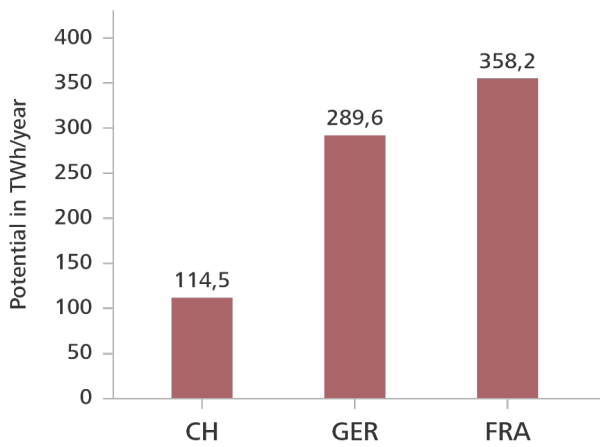


Fig. 3.6: Preliminary technical potential of AGRO-PV in the Upper Rhine Region (Najjar et al., 2022, 25).

Yearly Agro-PV Potential in the URR

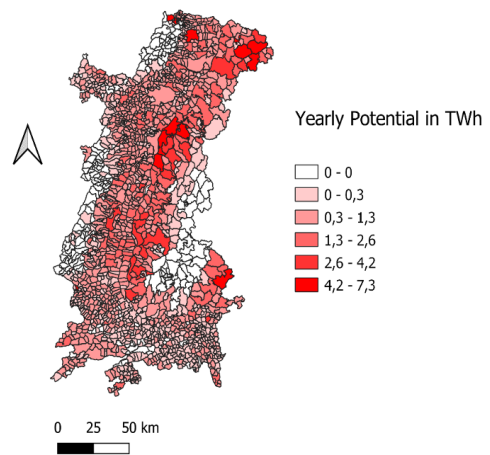


Fig. 3.8: The technical potential of Agro-PV per municipality of the Upper Rhine Region (Najjar et al., 2022, 24).

RES	Potential (in Twh)
AGRO-PV	91,5
GM-PV	68,0
Rooftop PV	52,2

Tab. 3.4: The technical potential after the spacing reduction factor for AGRO-PV and GM-PV was included in Najjar et al. (2022)

The estimated technical potential is large (159,5 TWh/yr), but only a small percentage of agricultural fields and grassland might be covered with PV installations, due to other constraints that can be factored in when calculating the economic and feasible potential as mentioned earlier. Reasons for reduced potential could be the impact on landscape, biodiversity and food production. (Vrinceanu et al., 2019). However, if only 20 % of the technical potential can be utilised, a significant energy contribution to the total energy demand of nearly 42 TWh per year is possible.

3.1.3 Hydropower

The Rhine is considered one of the most important rivers in Europe. It connects the Swiss Alps, where it originates from, with the North Sea and its catchment area spreads over nine states. In addition to hydropower, its major functional uses include navigation, agriculture, and water supply among many others. Because of navigation, hydropower, and flood protection surfaces, there are numerous hydraulic structures on the Rhine that have been built to regulate the water level of the mainstream water body. These structures can be in the form of locks, impoundments, and dikes. The phenomenon called “hydropeaking”, which happens during consumption peaks, when hydropower plants adjust the water supply to accommodate the power supply, directly impacts the flora and fauna. (ICPR, 2015).

The negative effects on the Rhine River system due to the aforementioned structures have been investigated widely in the ICPR report 2015, but are beyond the scope of this report on the existing infrastructures. If new or enhanced infrastructures are planned then the environmental aspects will have to be taken into consideration.

Trion-Climate conducted a study in the Upper Rhine area along the Rhine about the built-up potential of renewable energy related installations and established a best practice map. When it comes to hydropower, there are numerous installations of hydropower plants along the German-French and the German-Swiss border. The German-French hydropower plants are: Kembs, Ottmarsheim, Fessenheim, Vogelgrün, Marckolsheim, Rhinau, Gerstheim, Strasbourg, Gamsheim, and Iffezheim. The last two power plants mentioned are operated by both Germany and France. They have an overall installed capacity of 1450 MW. The Swiss-German hydropower plants are: Birsfelden, Reckingen, Albbruck-Dogern, Laufenburg, Säkingen, Ryburg-Schwörstadt, Rheinfelden, and Augst-Wyhlen. Two of the 8 hydro-power plants (Ryburg-Schwörstadt and Augst-Wyhlen) are operated by a German-Swiss energy company. They have a joint capacity of approximately 635 MW. (TRION-Climate e.V., 2019).

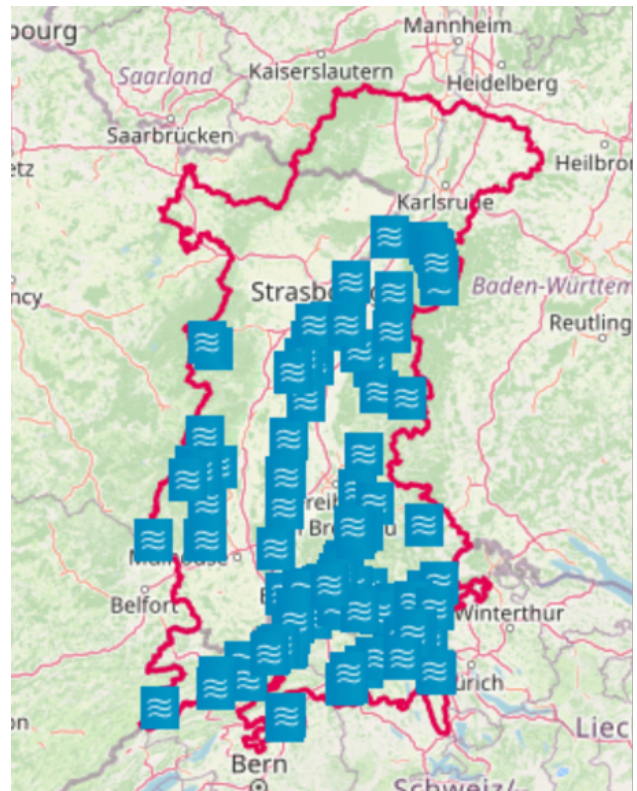


Fig. 3.9: Hydropower stations' map along the Rhine in the Upper Rhine region (TRION-climate, GeoRhena 2020).

Fig. 3.9 presents the density of the hydropower infrastructure along the Rhine (TRION-climate, GeoRhena 2020).

In the Alsace region, hydropower is already extensively used with a lot of energy produced by installations on the Rhine. The Directorate of Agriculture, Tourism and the Environment of the Regional Council of Alsace (Dafté) stated that extra kWh shouldn't be built at the expense of biodiversity or stream life. Therefore, the Regional Council of Alsace along with the Agence de l'Environnement et de la Maîtrise de l'Énergie (ADEME) has been financing studies to evaluate the repowering of old turbines even if their production capacity is not optimal. The published article also states that micro-hydropower installations could also contribute to the future energy system of the region if engineering costs could be adjusted by EDF in favour of micro-scale projects (Banque des Territoires, 2010).

On the German side of the Rhine, EnBW is an electric utility company in Baden-Württemberg. According to its website, in Germany, the potential of hydropower is nearly exhausted as there are no possible new locations for large hydropower plants. In order to achieve an increase in production, the focus is on replacing, expanding, and modernising the already existing power plants (EnBW, n.d.).

Axpo is the largest energy company in Switzerland and according to its website, it is also the largest Swiss producer of renewable energy - a large portion of which is hydropower. According to an article published on their website, on the Rhine stretch between Schaffhausen and Basel, where the Rhine flows on the border between Germany and Switzerland, there are already 11 power plants (8 of which are located in the URR). Also, according to Axpo, there is no more space on this route for additional power plants and the only possible solution would be to increase the efficiency of the already existing plants (Axpo, 2018).

In conclusion, the same observation can be found in the statements of experts and energy producers in the three countries; the hydropower potential is nearly exhausted in the study region specifically on the Rhine and the way forward is through improving the efficiency of the already existing power plants.

As for the hydropower potential 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 per year (Fig. 3.10).

Hydropower Potential per Border



Fig. 3.10: The current potential of hydropower in the Upper Rhine Region (Najjar et al., 2022, 26)

The result of the investigation shows that the contribution of hydropower to the energy transmission will be quite limited, because the produced electricity is already used for power supply today.

3.1.4 Bioenergy & Biomass

Biomass is used increasingly nowadays to substitute fossil fuels in the transport and the energy sectors. It has the advantage of regional availability in Europe in comparison to fossil fuels and its ability to be stored in comparison to the intermittent renewable energy sources like wind and solar. Its future demand is expected to rise because of the depleting fossil fuel reserves and their decreasing availability, political incentives, and changing consumption patterns. On the other hand, increasing biomass usage is accompanied by numerous social challenges like public acceptance and sustainability challenges such as land use competition, resource overexploitation and mono-cropping, biodiversity losses, soil degradation, and air and water pollution. However, because the national goals of the three countries align in the need to increase the production of renewable energy, biomass will have to contribute as well (Schumacher et al. (Eds.), 2017).

The project "Biomass OUI" studied the biomass potentials of the Upper Rhine Region, ran over the course of three years, and was completed in July 2015. The project was composed of six individual research areas systematically looped together - each of which relied on the expert contributions of a large number of scientists from different disciplines and backgrounds. The contributors included economists, engineers, forestry scientists, physicists, biologists, chemists, geographers, and sociologists from prime research institutions across the tri-national region. Moreover, as part of the project, this network of scientists interacted with a large number of stakeholders in the industry and in politics in addition to NGOs and civilian groups of the region through various stakeholder workshops throughout the project in order to make the study more comprehensive, relevant, and realistic. The main themes of the six research areas included studying the biomass resources and land use change, biomass value change and logistics, biomass conversion pathways, biomass scenario development and analysis, and biomass sustainability impact analysis. All these themes converge in order to establish a roadmap for sustainable biomass utilisation in the URR. The output of the project was the publishing of a report called: "Innovations for Sustainable Biomass Utilisation in the Upper Rhine Region" which described the methodology used and the outputs of the different research area groups (Schumacher et al. (Eds.), 2017).

According to Rudi et al. (2017, Abstract), "Valorisation of biomass as a source of energy is challenging due to the large variety of biomass feedstocks and conversion technologies." In other words, the calculation of the biomass potential is not as straightforward a task from a methodological perspective as calculating the potential of wind energy or solar PV because bioenergy can be attributed to different sources (woody biomass, manure, energy crops...) that can also be imported into the region and exported out of it. Moreover, these sources can be matched with a range of different technologies and con-

version pathways (anaerobic digestion, combustion...) that produce different outputs (heat, biogas, bioethanol, biodiesel...). Also, the location of biomass plants does not necessarily have to be in the vicinity of the biomass sources. Therefore, because the "Biomass OUI" project is a heavily researched and comprehensive project with concrete outputs, it was used as a basis for the RES-TMO's mapping of the biomass potential of the URR.

In fact, the first research group (RA1) had the task of identifying local biomass resources and land use conflicts in the Upper Rhine Region. 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 of this group 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". Additionally, the forest areas were geographically mapped and their wood yields were statistically determined. The amounts of secondary biomass such as "organic household waste, bulk waste, green waste, and vineyard residues" which make up a portion of organic waste were also calculated. The outputs determined by this group were an estimated technical biomass potential and these outputs were consequently later used as an input for some of the other research areas (Schumacher et al. (Eds.), 2017). RA1 also published a report, "Synthesis Report on Current Resources of Land and Biomass to Produce Bioenergy in the Upper Rhine Region (URR)" which explained the methodology and defined the terms used by the scientists to collect and map the information.

The bioenergy potential that can be produced by the different biomass sources is presented by source for the Upper Rhine Region in table 3.5. The unit for the potentials is kWh per capita which is different from what has been calculated for the other RES as these values are based on the Biomass OUI Project.

Biomass Potential Category	Yearly Value (in kWh/capita)	Country/Region
Energy Wood	520	Germany
Energy Wood	400	France
Energy Wood	570	Switzerland
Agricultural Residues	170	The URR
Manure	30	The URR
Organic household waste	36	The URR
Green waste	50	The URR
Sewage sludge	50	The URR

Tab. 3.5: The bioenergy potential per biomass source in the Upper Rhine Region (Schumacher et al. (Eds.), 2017) (Najjar et al., 2022).

The unit of the calculated potentials is given per capita; therefore, the calculated potential and its geographical distribution does not depict the physical location of the biomass but rather its potential per URR citizen. In the case of agricultural residues, the report confirms that the number is 170 kWh/ca. represents the energetic content of 50% of the agricultural residues in the URR and in fact at the moment, agricultural residues are not used for bioenergy production. In addition, the value of 30 kWh/ca. attributed to manure is the potential that arises from processing 50% of the manure generated in the URR in biogas plants. When it comes to generated household and bulk waste, it is mainly incinerated and is considered to be only 50% renewable. It has to be mentioned that the study also highlighted that the energy resources for wood residues is already exhausted (Najjar et al., 2022).

Najjar et al. (2022) converted the results mentioned in the table above to TWh per year to make the energy potential results comparable to the other investigated RES. In Fig 3.11 the technical biomass potential in the Upper Rhine, as described in the OUI Biomass report (Schumacher et al. (Eds.), 2017), is converted into TWh per year and the distribution of the technical potential is presented per French department, German Stadt/Landkreis, and Swiss Canton.

Yearly Biomass Potential in the URR

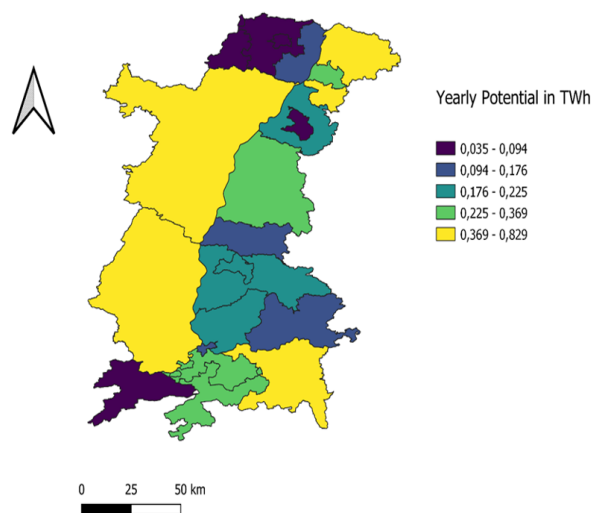


Fig. 3.11: Technical biomass potential in the Upper Rhine Region as derived from the project Biomass OUI in TWh/y (Najjar et al., 2022, 27).

3.1.5 Geothermal

“Geothermal energy sources can be differentiated into technologies utilising the shallow subsurface (10s to 100m depth) and methods exploiting the deep subsurface (1000s of metres depth) for energy extraction. Shallow geothermal energy is commonly used to supply heating or cooling energy, while deep geothermal energy can be employed for both electricity generation and space heating” (Miocic., 2021). In the following section, the potential for both types of geothermal energy in the TMO region is briefly explained.

“Shallow geothermal energy systems generally take advantage of the constant temperature of the shallow subsurface (~10°C) and, coupled with heat pumps, are predominantly used for heating and cooling family homes (Sarbu, Sebarchievici, 2014). Climate, with cold winters and hot summers being advantageous, and electricity prices and sources determine whether ground source heat pump (GSHP) systems are more cost-effective than conventional heating systems. The combination of GSHPs with electricity from other types of renewable energy (solar, wind) allows for a significant reduction of the carbon footprint of heating and cooling residential buildings. The Vosges Mountains and the Black Forest experience cold winter months with the average temperature dropping below 0°C from December to February, making borehole heat exchangers more efficient than air-water heat pumps. Contrarily, the lowlands of the Upper Rhine area have warm summers (around 20°C) and in recent years have commonly experienced heatwaves with tropical nights, highlighting the potential of shallow geothermal energy for cooling. There are already several 10.000s of GSHPs installed in the TMO region, predominantly in the German and Swiss sections. However, there are several 100.000s of single-family homes in the region which could be heated and cooled with GSHPs, in particular when combined with a future-proof low-energy renovation. Thus, increasing the share of GSHPs used in the TMO will enable a drastic reduction in carbon emissions related to space heating and cooling” (Miocic., 2021).

Deep geothermal technologies produce waters with temperatures in the range of 100 to 250°C for district heating and electricity generation (Barbier, 2002). The efficiency of deep geothermal wells is dependent on how deep hot fluids are encountered as well as the properties of the rocks the fluids are sourced from. Geologically, the TMO region is dominated by the major rift of the Upper Rhine Graben (URG) with the Vosges and Black Forest mountains forming the Graben shoulders to the West and the East of the North-South oriented Graben structure (Dèzes et al., 2004). As a result of the rifting and the associated crustal thinning, the URG has a high heat flow density which leads to high temperatures in the relatively shallow subsurface, and thus represents an ideal region for deep geothermal exploitation (Harlé et al., 2019). The first scientific geothermal wells in the URG were drilled in the late 1980s in Riehen (Switzerland) and the early 1990s at Soultz-sous-Forêts (France). At the latter location a pilot geothermal power plant was installed subsequently and started producing electricity in 2010 (Sanjuan et al., 2006). Currently, there are nine geothermal energy plants operating or in construction in the TMO region, producing 22 MWel and 101 MWth (TRION-Climat e.V., 2019). The theoretically recoverable heat in the rocks that lie at a depth shallower than 7000 m depth in the URG is in the order of $7.4 \cdot 10^{12}$ GJ (GeORG-project team, 2013), which is equivalent to $2 \cdot 10^{12}$ MWh. While only a fraction of this energy is technically recoverable, there is an enormous potential for both heating and electricity generation from deep geothermal power plants in the TMO region. One of the main issues related to exploration and production of deep geothermal energy in the URG is the complex geological situation and the need for reservoir stimulation in the tectonically strongly affected region, which has more or less stopped the construction of deep geothermal infrastructures. According to the study carried out within the GeORG project, 25% of the heat request in the URG could be covered by shallow geothermal infrastructures Fig 3.12 (Miocic, 2021).

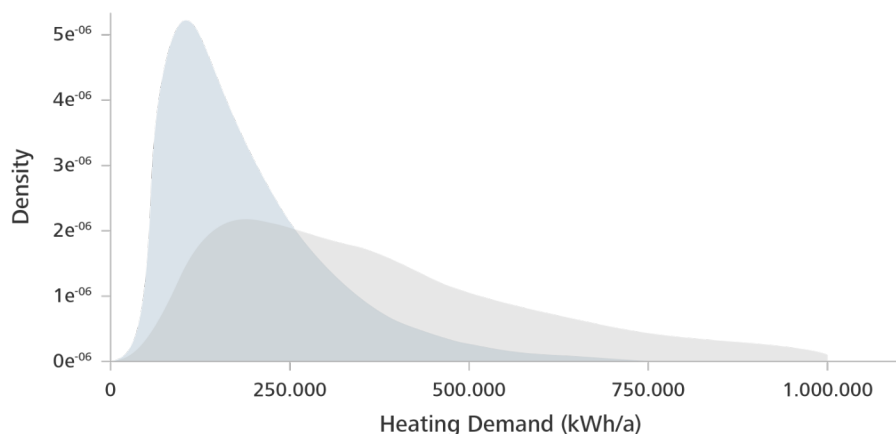


Fig. 3.12: Geothermal potentials in comparison to heating demands for shallow geothermal (Miocic, 2021).

3.2 Overall technical potentials in the Upper Rhine without geothermal

The sum of the technical potentials calculated above (including the refinements for wind and solar) amounts to 358,5 TWh. (Tab. 3.6) The wind and solar PV potentials were also validated by comparing them to other results obtained in the RES-TMO project. (Najjar, 2022) The calculated potential could cover 100% of the total energy demand of the Upper Rhine (212 TWh/year) without even considering the geothermal potential. In general, it can be observed that the largest potential is for solar PV (211,7 TWh). The second largest potential in the region is wind (128 TWh). For wind, the total usable area is about 15.5% of the total URR area. According to Fraunhofer ISE (Ed.) (2020), PV and wind power are considered pillars of the future energy supply. They constitute the bulk of the region’s potential.

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

Tab. 3.6: Yearly Technical URR Renewable Energy Potential by Source (Najjar et al., 2022)

However, it is clear that only a small percentage of the technical potential is usable due to legal, social and economic reasons. In addition, there are some methodological limitations for the estimations such as:

Wind: When it comes to wind energy, limitations in the methodology include the focus on yearly timescales that don’t take into consideration the monthly variations in wind energy potential that could vary significantly between the different months of the year. However, for the purpose of this task, yearly averages help in the estimation of the average yearly potential.

Solar: The initially calculated potential for free-range PV was overestimated as it took into consideration the whole area that is available without accounting for the installations and the significant spacing requirements needed for equipment, activities related to agriculture or even maintenance purposes. However, the spacing factor was considered at a later stage of the RES-TMO project and is included in the modified potentials found in Tab. 3.6. Moreover, the different needs and preferences of crop types and the effects that free-range PV could have on them have not been con-

sidered. Floating PV was not looked into and solar panels along transport lines were not considered separately (Najjar et al., 2022). Historical buildings were not factored out in the rooftop potential. As discussed in the methodology section, the rooftop potential usable area consists of clusters of buildings for technical purposes, so it was not possible to subtract historical buildings and structures. However, this is not a critical criterion as for example in Switzerland, it is possible to install but better not to significantly interfere with historical buildings as per the website, Sonnendach². The roof load bearing capacities were also not considered because the calculations should be performed on a case-to-case basis for each roof and are part of the feasible potential (Tab. 2).

Biomass: When it comes to biomass, the limitations are defined by the limitations of the data acquisition part of the Biomass Oui project and are mainly related to the heterogeneity of the available information from the three different countries due to different factors including confidentiality. Moreover, the smallest level of detail could not be achieved in France for example, which meant that the results could not be portrayed at the lowest level of the arrondissement, Kantone, Landkreise (Weber et al., 2014).

Legal: The main limitations, when it comes to calculating the solar and wind potential, stem from the tri-national nature of the region and specifically the difference in regulatory structure. For example, in the German state of Baden-Württemberg, a clear definition of the areas that are restricted for PV and wind dissemination are found in the form of a document with the title, “Kriterien Katalog” (a criteria catalogue), on the website Energy Atlas Baden Württemberg³ which lists the hard restriction areas that are considered a forbidden zone for the propagation of wind and solar farms and a conditionally or partially restricted zone which can be utilised in theory. In France, as it was determined by our expert opinion, when it comes to renewable energy projects, the decision and study is made on a case-to-case basis and an extensive environmental impact assessment study should be completed. In Switzerland, GM-PV projects are in general not recommended and the focus of PV propagation is on rooftop installations (EEA et al., 2019).

As mentioned above the technical potential does not depict the potential which can be realised in reality because it is limited to a large extent by factors such as land-use competition due to food production, environmental impacts, landscape aspects, societal acceptance, economic framework conditions, regulations and others. Nevertheless, the technical potential supports the development of better frame conditions and free spaces to better exploit the potentials in an integrative process with strong participation of citizens

² <https://www.sonnendach.ch>

³ <https://www.energieatlas-bw.de>

and enterprises. If 20% to 30% of the overall technical potential could be activated in the long term, this would be a strong contribution to total energy needs in the URR, including not only electricity but also the heating and cooling demand. Citizens' resistance to the implementation of RE tech-

nologies is different in the three countries (Wüstenhagen et al., 2007). Therefore, it is important to include them in the decision-making process so that the transition into the future energy system will be smoother.

4. Green Batteries with Circular Economy

Lithium-ion batteries (LIBs) are a key technology for a sustainable energy sector without CO₂ emissions. The competence group Green Batteries describes possible projects connected to a circular use and recycling of batteries that could be realised in the region of Fessenheim.

The synergies of the competence group "Green Batteries with Circular Economy" and the competence groups "Green Hydrogen" and "Smart Electricity Grids" will also be addressed in this chapter.

4.1 Background

A circular economy for battery materials, as promoted for example by the EU Circular Economy Action Plan (EC, 2020), is important for several reasons:

- The availability of LIBs is limited because they contain critical raw materials (e.g. cobalt, nickel and natural graphite); therefore, reusing materials from batteries at their end of life (EoL-batteries) is crucial to becoming independent from countries that mine these materials and in helping to secure a safe supply chain.
- Most raw materials are not mined in Europe, so transporting them is an energy intensive process; however, the materials from EoL-batteries are already available in Europe, so transport distances are much shorter and less energy consuming.
- By implementing a circular economy, all concerned industries will be located in one place (e.g. the Fessenheim region) which leads to the reduction of transportation distances for all relevant battery components and the decrease in the carbon footprint of batteries.
- Providing electricity exclusively by renewable energy-sources (RES) urgently requires more electrical energy-storage (EES). Batteries, e.g., old batteries from electric vehicles (EV), are one of the most promising technologies that are suited to this purpose (2nd-life application).

At the moment, recycling of battery materials focuses on regaining the original raw materials that are used for the synthesis of new active battery material. This is done using high energy-consuming processes and therefore, recycling has a negative impact on the carbon footprint of the battery.

The recycling of battery materials is still in its infancy, since EoL-batteries from EVs, that are needed for the recycling processes, are still scarce. With more and more EVs entering the market this field is becoming extremely important for the future and holds a lot of potential for the industry.

As described in the following text and according to the local and regional assets described above, conditions are suitable for setting up the battery industry in Fessenheim.

Facilities that recycle or produce battery materials need a lot of electricity. As described in Chapter 3, the Upper Rhine valley has a vast potential for generating electricity from wind and PV. These RES will help provide cheap and CO₂-neutral electricity for the corresponding facilities. This is a crucial requirement for setting up an industry with a low environmental footprint.

Furthermore, the already existing grid-infrastructure of the old nuclear power plant can be useful for suggested pilot projects like the "Utility-Scale Hybrid Electrical-Energy Storage, complemented with 2ndlife EV Batteries" (see below), which is important for the extended use of RES. Setting up the envisioned facility on the site of the old nuclear power plant would therefore be reasonable, but it is not a prerequisite for the establishment of a second life battery-storage utility.

Another important advantage of the Fessenheim region is the already existing infrastructure for the transportation of goods. This is especially important for suggested pilot projects that deal with battery recycling and battery material production. The different facilities depend on such an infrastructure, e.g., the transportation of EoL-batteries to an envisioned recycling plant. As mentioned in the intro-

duction, the ports nearby provide connections with many relevant companies along the Rhine. An example of this is the BASF in Ludwigshafen, which has been involved in the production of battery materials for LIBs for a long time. In addition, the previously mentioned European transport corridors Rotterdam-Genoa and Marseille-Basel-Rotterdam provide a unique European transport infrastructure which also connects to global markets. This infrastructure is a very important factor in today's globalised economy.

From a social, but also economical perspective the installations envisioned within the pilot projects of the green battery group will provide many jobs in the Fessenheim region. Because the transformation of the energy sector towards CO₂-neutrality is politically supported, jobs connected with this will be safe for a very long time since they are linked with the European lead in innovation technologies to achieve CO₂ neutrality, and can therefore be denoted as future-proof jobs.

4.2 Scope of the Competence Group Green Batteries

The competence group Green Batteries evaluates the potential of the Fessenheim region to turn into an innovation region covering all aspects of the circular economy for batteries. This includes the production of battery materials, the 2nd-life utilisation of batteries from electric vehicles (EVs) as well as the recycling of these batteries after their 2nd-life utilisation (Fig. 4.1). Additionally, a utilisation-scale battery for electrical energy storage (EES) is included in the evaluation.

Facilities that represent a part of a circular economy usually have several interfaces that exchange know-how and materials, which are discussed in detail later in this chapter. In fact, transportation can be reduced drastically, if these facilities are located close to each other. This is not only financially attractive, but it also saves CO₂-emissions.

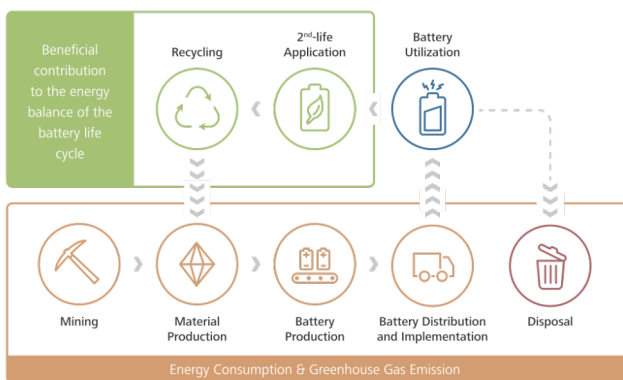


Fig. 4.1: Lifecycle of a battery (Dühnen et al., 2020: 3).

The subgroups (see chapter 4.3) identify potential interfaces which are important for the industry among their activities.

4.3 Subgroups of the Competence Group Green Batteries

The competence group “Green Batteries” is divided into four subgroups:

- I. Battery Materials
- II. Batteries for 2nd-life energy storage
- III. Battery Recycling
- IV. Economic Impact of Batteries

The subgroups work on specific pilot projects that could be realised in the region of Fessenheim and could result in possible pilot projects. The subgroup “Economic Impact of Batteries” does not suggest pilot projects itself, but supports the other subgroups. Fig. 4.2 gives a brief overview of the possible installations (pilot projects) envisioned by each subgroup and shows the connection between them.

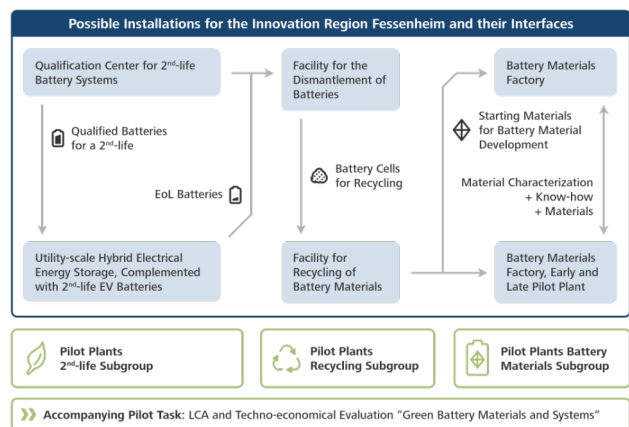


Fig. 4.2: Pilot projects developed by the Green Batteries group and their interlinkages

4.3.1 Focus of the “Battery Material” Subgroup

Research on new and refined battery materials is an ongoing task which has been driven by improving the performance of the batteries in the last decades (higher energy density, higher power output, longer cycle life and so forth). Although these parameters are still important and need to be further improved, the focus is shifting towards “green” battery materials that are sustainable. Sustainability can be achieved by finding/refining materials based on amply available elements as well as developing processes for their preparation with a low CO₂ and environ-

mental footprint. Developing more sustainable battery materials will remain important in the future and includes almost every battery component; for example, cathode and anode active materials as well as all the inactive supporting materials. The composition of the required materials will also be influenced by the recycling aspect, the new recycled material flow and vice versa. Potential pilot projects and projects that offer room for innovation in the required materials are developed by this subgroup. For a sustainable energy sector, which is a part of the “European Green Deal” (EC, 2019), such pilot projects strongly promote the long term vision of a sustainable innovation region.

4.3.2 Focus of the “Batteries for 2nd-Life Energy Storage” Subgroup

The widespread use of electric vehicles (EVs) towards a mass market is essential to reduce emissions of pollutants and greenhouse gases in the transport sector. However, the production of vehicle batteries is still very energy intensive. So, the advantages of electromobility in terms of CO₂ emissions will only become evident after a long service life of the batteries and correspondingly more kilometres being travelled with these vehicles. Due to the ageing (capacity fade and increase of inner resistance) of the lithium-ion batteries used in an EV, the range and performance of the latter decrease over their service life. However, a necessary replacement of the battery in the vehicle does not necessarily mean the end of battery operation. It can be further used in a 2nd-life application and still provide sufficient capacity, e. g. at lower power rates. The CO₂ balance is thus improved, considering the longer service life of the battery.

As 2nd-life applications, various different concepts can be considered and are currently investigated within demonstration projects. In so-called behind-the-metre applications (residential, commercial & industrial) stationary buffer storage combined with PV systems can, for example, increase the self-sufficiency rate (IRENA, 2019). The buffer storage can also be used to reduce peak loads, support load shifting and provide grid services. Such revenue stacking strategies improve the economics of stationary storage investments. Furthermore, large-scale buffer storage can be coupled with PV or wind power plants and can be installed at old sites, where conventional power plants have been recently shut down (e.g., in Fessenheim) and where the electrical installations and grid connections can be ideally used for such centralised storage plants. For such large-scale storage installations, hybridisation of different technologies can be an interesting concept as site-specific requirements and the corresponding operating control strategies can vary depending on the business models and regulatory framework in place. Exemplarily, (2nd-life) batteries can be coupled with grid-scale / large-

scale storage units such as redox-flow batteries, high-temperature batteries and even Carnot batteries. Besides this huge variety of stationary applications, used EV-batteries are meanwhile also of interest for floor-borne vehicles (e. g., forklifts), on grounds of economic considerations. Although opportunities for 2nd-life storage are impressive, challenges have to be tackled in terms of qualification for re-utilisation, prediction of the remaining useful lifetime and development of efficient dismantlement strategies. Within the Innovation Region Fessenheim a pilot for 2nd-life battery qualification can be established and later transferred as a model for decentralised 2nd-life qualification stations.

4.3.3 Focus of the “Battery Recycling” Subgroup

After a period of first and second life, each battery reaches its end of life (EoL) state. To achieve a circular economy, these batteries must be regarded as a source of (critical) raw materials. The individual process steps, starting from the evaluation of a 2nd-life potential for battery systems, modules, and cells to the disassembly steps to separating the material fractions and processing the active material, are separated into pilot projects. Several recycling approaches are already implemented on an industrial scale. However, there is still a lot of potential for optimising the disassembly process in terms of safety and efficiency; in addition to the comminution, sorting technologies, recovery rate, and recycle quality.

Currently, the disassembly is a manual process in all known recycling plants. Several public-funded projects deal with robot-automated disassembly for the purpose of separating all parts in a non-destructive (smart) way. In this case, robots need to be inputted with data specific to each battery type. The present approaches are categorised by dismantling type, as smart or robust. The robust approach considers destructive separation in favour of lower sensitivity and higher efficiency.

The challenge of the following steps in the recycling process is the generation of pure fractions, especially in the case of active materials. The performance of lithium-ion batteries is highly dependent on high quality anode and cathode materials. Small amounts of impurities, defects and structural failure lead to a functional decrease and lower the performance of a battery. Therefore, each step of the recycling process is crucial to the quality of the output fraction, the type of mechanical shredding, intelligent sorting with mechanical and sensor-based technologies, and tailored chemical and thermal treatment of the black mass. In-process analysis and recycle analysis need to be linked with feedback from the cell manufacturer/developer implementing these recycles. Intelligent recycling infrastructure will be needed at several places

within Europe, in order to return valuable materials back into the production process. These places need to be strategically selected according to the best frame conditions provided by the Upper Rhine.

In the strategical context of the Innovation Region Fessenheim, battery recycling is one of the building blocks that can be used for establishing battery plants and facilities where research can be linked to the actual application of renewable energy, energy storage and green-hydrogen production and usage.

4.4 Interfaces with the other Competence Groups

Interfaces with the other competence groups – Hydrogen and Smart Grids – are evaluated. Fig. 4.3. shows the major interfaces of the installations (pilot projects) envisioned by the Green Batteries group with the other competence groups.

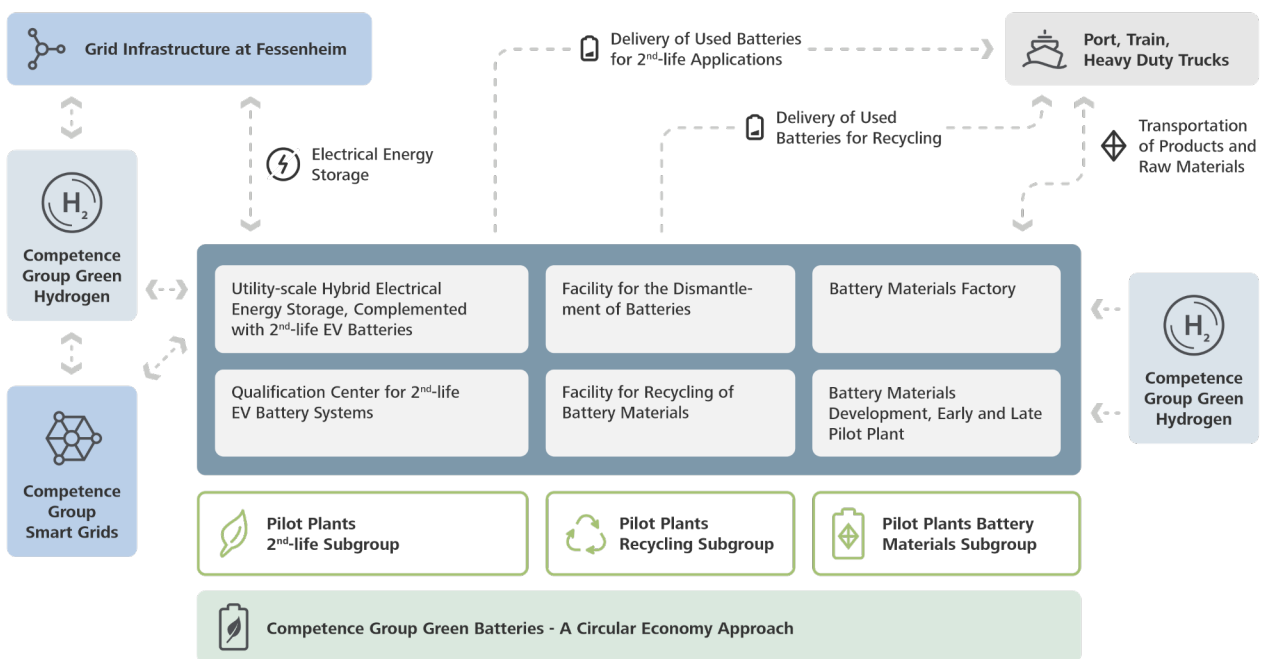


Fig 4.3: Interfaces between the Green Batteries Group’s envisioned installations (pilot projects) and the other competence groups as well as the importance of the harbour at Fessenheim

The installation of electrical-energy storage, as envisioned by the 2nd-life subgroup, is directly related to the establishment of a smart grid.

Additionally, all installations dealing with the energy-intensive development and production of battery materials can profit from the electrolysers envisioned by the Hydrogen Group. Electrolysis produces oxygen, which is required for the synthesis of cathode-active materials (CAM), as a by-product.

4.5 The Future of Green Batteries in the Fessenheim Region

As already mentioned, there is a lot of potential available for a successful implementation of green-battery facilities in the Fessenheim region. However, some demands, and challenges remain. The following paragraphs will show what is already available and what is still needed.

4.5.1 Status

A lot of expertise as well as R&D support regarding technologies for a circular economy of batteries is already available in the Fessenheim region to assist companies that are willing to invest in such facilities. However, companies, especially large ones, that produce and further develop such technologies, are not yet linked together.

4.5.2 Potentials

Transport Infrastructure and Location

Every production facility requires a well-developed infrastructure and access to logistically important trading hubs. The study revealed the outstanding importance of the Rhine and the existing ports in the Fessenheim region for the shipping of batteries and refined materials from all other areas in Europe.

A holistic approach including battery and hydrogen technology combined with a smart grid is a huge advantage because of the many interfaces that connect the different areas.

Jobs

The installations, envisioned by the Green Batteries Group, have the potential to generate future-proofed jobs in the Fessenheim region. These jobs need multifarious areas of expertise in the field of batteries such as battery-material production and characterisation as well as knowledge about recycling and characterisation of batteries. Due to the universities and research institutes located in Switzerland, France and Germany that teach all the relevant competencies, people with the required expertise are already in place in the Fessenheim region. Their presence also helps to develop and offer training courses to advance the knowledge of employees that were employed at the nuclear power plant and previously held technician and service level jobs. In that way, these employees can be easily integrated in future working fields.

Available Competences and Expertise

The Fessenheim region conveniently encompasses available expertise concerning battery materials, represented by universities, research institutes and companies located in Switzerland, France and Germany each with special competencies (Fig. 4.4). Advantageously, this supports the intended pilot projects that will need R&D-support from these institutions for successful work.

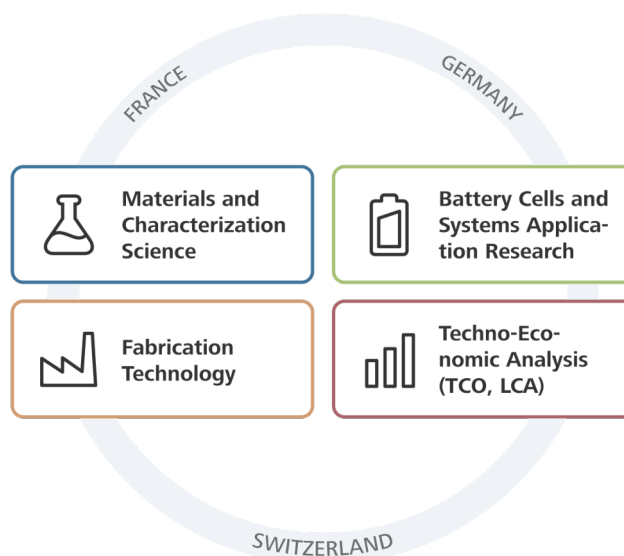


Fig. 4.4: Complementary Competences of the Competence Group Members that are available in the Fessenheim Region

The Innovation Region Fessenheim will focus on aspects of battery innovations that are not yet represented within the scientific landscape of Germany by utilising the available expertise found abundantly in the region. Additionally, links may be formed with the already existing competence centres in Ulm (HIU), Münster (FFB) and the institut Carnot Mica in Mulhouse – a future network between these competence centres will be envisaged.

4.5.3 Challenges

Companies

The motivation and conviction of companies to invest in installations in the Fessenheim region is the biggest challenge for a successful transformation of the region. In particular, a large sized company that is willing to participate in the building and operation of some of the envisioned installations would be very important. Smaller companies are more likely to follow suit and build supporting/complementary facilities in the Fessenheim region.

As a result of several meetings with interested industry partners, the following questions arose; they need to be addressed as comprehensively as possible as that might be crucial to the decision of a company considering an investment in a factory or installation in the Fessenheim region:

- Is it possible to get special frame conditions, like cheap loans or tax releases for the construction of a factory?

- Is it possible to get special conditions for the designated areas needed to install a factory?
- How many new industrial areas are available? When are they available and how big are they?
- What is the local infrastructure like at the designated areas?
- How expensive is local energy?
- Is there enough renewable energy in the area available, and if not what is the infrastructure available to transport green energy to the area? Are tax releases possible to have competitive energy costs, regarding the actual fluctuations?

4.5.4 Demands

Funding

Investments by private companies must be supported by suitable, holistic funding schemes. It is best, this be achieved through EU investments as part of the “Green Deal” (EC, 2019). Additionally, other funding schemes need to be identified or, best, be implemented through politics. All the described pilot projects have the potential for individual funding. Most of them fit well with current national and/or European tenders, but there is always a risk of competition from other project ideas.

Unlike most other public funded projects, the focus of all the present pilot projects is the implementation of demonstrators, pilot projects, labs etc. in one place. Therefore, the individual projects have above-average needs for investment. The budget estimation for the first setup of the pilot projects for a dismantlement plant, a recycling plant and a hybrid storage consisting of 2nd-life LIBs, a NAS battery, a vanadium redox-flow battery and a Carnot battery is estimated at €250 Mio. Additionally, for the planning phase of approximately five years €10 Mio. is needed for a professional project-coordination team.

Embedding of the Pilots into the Regional Innovation Concept

As discussed earlier, the installations suggested by the Green Batteries Group should be in close proximity to the port at Fessenheim or at least be well connected to it. Therefore, areas have to be identified, where the proposed installations can be realised.

4.5.5. SWOT Analysis of the Overall Concept

A SWOT analysis for each pilot project/plant can be found in the corresponding descriptions (see Pilot summary).

4.6 Pilot Projects

The pilot projects, envisioned from the different sub-groups, will be presented in short with a rough timeline. Detailed descriptions of corresponding pilot projects can be found in the Pilot summary. In addition, a list of concerned companies is included at the end of this chapter.

4.6.1 Batteries for 2nd-life Energy Storage

The developed concept of 2nd-life storage is embedded in a holistic approach. Fig. 4.5 gives an overview on the logistics, qualification for re-utilisation, set-up of pilot projects for dismantlement and recycling as well as the design and installation of stationary battery-storage consisting of aged EV-LIBs. In total, the process is divided into seven sub-pilot projects (see Pilot summary).

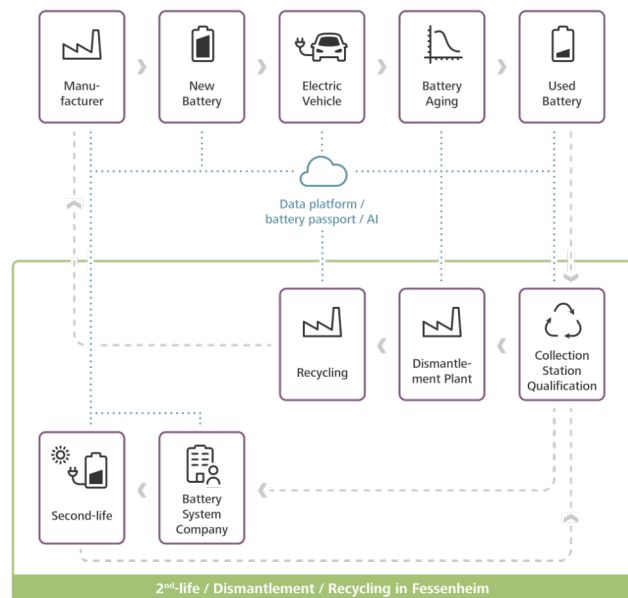


Fig. 4.5: Holistic approach of qualification, re-utilisation, dismantlement and recycling of aged electric vehicle batteries

For the realisation of the suggested 2nd-life battery pilot projects, the subgroup envisions the installation of two plants in the Fessenheim region:

A. 2nd-life EV Battery System Manufacturing

- This facility is closely linked to the dismantlement facility described later by the recycling subgroup.
- The qualification of batteries is done in this facility. Depending on the state of health (SoH), it will be determined whether a battery is suitable for a 2nd-life application or has to be recycled directly.

B. Utility-Scale 2nd-life Battery Storage

- This battery storage consists of old batteries from EVs.

C. Utility-Scale Battery Storage

- In this hybrid battery storage, different storage technologies like redox-flow batteries, NAS batteries and a Carnot battery will be combined.

The “Utility-Scale 2nd-life Battery Storage” and the “Utility-Scale Battery Storage” combine various relevant stationary technologies for EES such as a vanadium redox-flow battery, a NAS battery, a Carnot battery (see Fig. 4.6) and shall be integrated into a grid-scale/large-scale hybrid electrical energy storage.

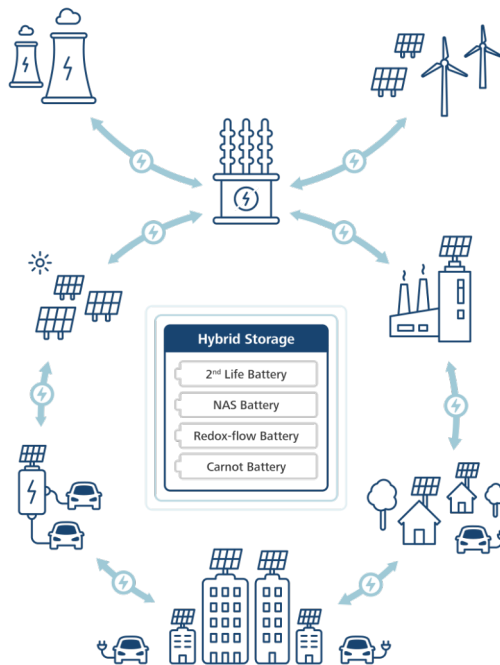
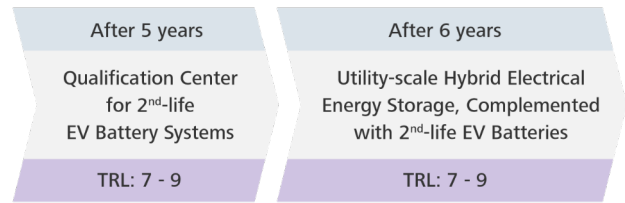


Fig. 4.6: Concept of grid-scale / large-scale hybrid EES consisting of second-life LIBs, a NAS battery, a vanadium redox-flow battery and a Carnot battery (edited from Gattiglio, 2017)

In Fig. 4.7 a timeline for the pilot projects suggested by the 2nd-life subgroup is presented.



- Years after the beginning of the project
- TRL: Technological Readiness Level of the technology addressed in the planned pilot project (1 = minimal; 9 = mature)

Fig. 4.7: Timeline and TRL for the installations envisioned by the 2nd-life subgroup

4.6.2 Battery Recycling

Battery recycling is the important link between 2nd-life utilisation of batteries and battery-materials production that enables a circular economy of the required materials. After a battery reaches its end of life (EoL), the valuable materials within the battery cells have to be recovered in a battery recycling plant. For this purpose, large amounts of old batteries are needed. Therefore, a close proximity to a facility that delivers batteries at their EoL would be a great advantage. The “Utility-Scale Hybrid Electrical-Energy Storage, Complemented with 2nd-life EV Batteries” - a pilot plant suggested by the 2nd-life subgroup - can provide batteries at their EoL, which would result in a great synergy between these two pilot projects. On the other hand, raw materials for battery-material production are produced at a recycling plant. Therefore, facilities that need these materials, along with all other pilot projects suggested by the Battery Materials subgroup, profit from having a nearby recycling plant.

The concept of the battery recycling subgroup includes dismantling (closely linked to 2nd-life) and recycling up to precursor materials for the production of new electrodes (Figure 4.8).

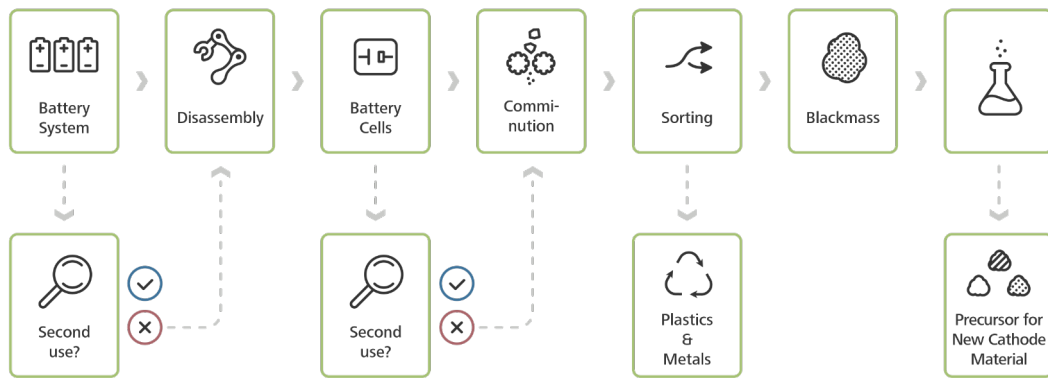


Figure 4.8: Approach of dismantlement and recycling of aged electric vehicle batteries including diagnostics

The purpose is the development of a full or semi-automated dismantlement plant including diagnostics at the different stages of dismantling (system, module and cell level). Development is required for the automation to open battery systems and disassemble to at least module level without special knowledge of the battery systems.

For battery cell comminution and fraction sorting, innovative mechanical and hydro-mechanical processes will be developed. The development focus is on high material selectivity, i.e., a minimization of impurities in each fraction, in particular the black mass. Subsequently, the “pure” black mass needs to be treated by a hydrometallurgical process. This step concentrates on the development of solutions combining suitability for the production of electrode materials and protection of the environment. The steps in the process that need to be further developed are highlighted in figure 4.9.

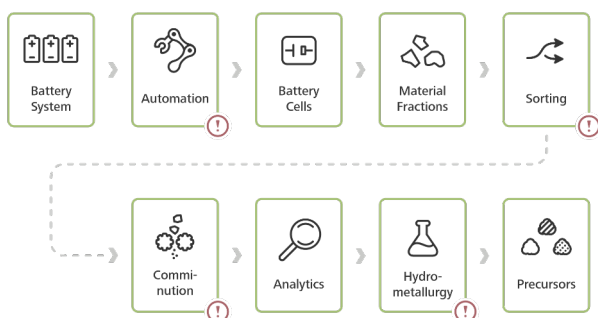


Fig. 4.9: Process steps in the dismantlement and recycling process that will be further developed for the planned pilot projects

The recycling subgroup suggests two pilot projects for the Fessenheim region where the suggested pilot projects (see Pilot summary) can be realised:

A. Facility for the Dismantlement of Batteries

- A dismantlement plant concept for used EV batteries (together with the 2nd-life subgroup)

B. Pilot Plant for the Recycling of Battery Materials

- Recyclate analytics and qualification concept
- Development of a mechanical process for highly material-selective comminution
- Methods for the hydrometallurgical recycling of the electrode materials

Fig. 4.10 shows a timeline for the suggested projects.

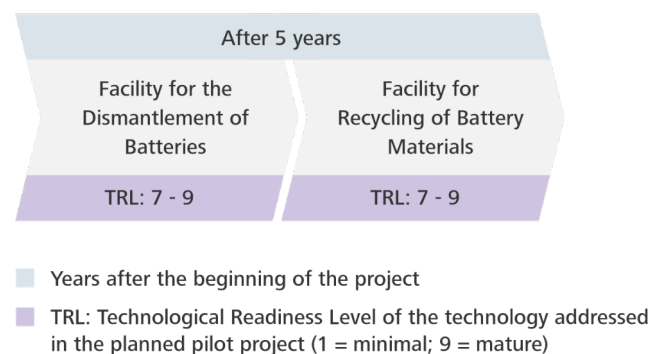


Fig. 4.10: Timeline and TRL for the installations envisioned by the recycling subgroup

4.6.3 Battery Materials

Nowadays, the major focus in the development of new battery materials and their production is on Lithium-ion batteries (LIBs). This is, due to their very good performance and the potential that still lies within this technology (e.g., utilisation of silicon or elemental lithium at the anode). Although a lot of research is done with respect to post-lithium chemistries, LIBs will dominate the battery market in the future, and it is not very likely that they will be completely replaced one day by another technology. However, the demand for electrical-energy storage (EES) will rise tremendously in the near future and LIBs will not be able to stem this on their own due to limited raw materials. It is therefore important to investigate new chemistries (e.g., organic materials, Al, Zn, Mg, and so forth) and further develop already existing alternatives like redox-flow batteries that can be used for special applications (e.g., large-scale EES). Therefore, the focus of the following pilot projects not only mainly represents the development and production of materials for LIBs, but it also presents the above-mentioned alternatives. Fig. 4.11 shows a timeline for the suggested pilot projects.

The battery materials subgroup suggests three pilot projects for the Fessenheim region:

A. Early Pilot Plant for Battery Materials (EPP)

- Deals with the development of battery materials with a low technological readiness level (TRL) of 1–6
- Will be closely linked with university laboratories in the Upper Rhine whose research outcomes can be interlinked to push the technological readiness level through joint projects

B. Late Pilot Plant for Battery Materials (LPP)

- Deals with the development of materials with a TRL of 7 - 9 and envisions a close cooperation with the EPP and the BMF
- Is strongly linked to the industry in order to implement field tests for production preparation and can be linked to innovation labs at the innovation park EcoRhena

C. Battery Materials Factory (BMF)

- Produces battery materials for sale and envisions a close cooperation with the late pilot plant for battery materials (LPP) to accelerate the production of novel materials

4.7 Summary and Recommendations

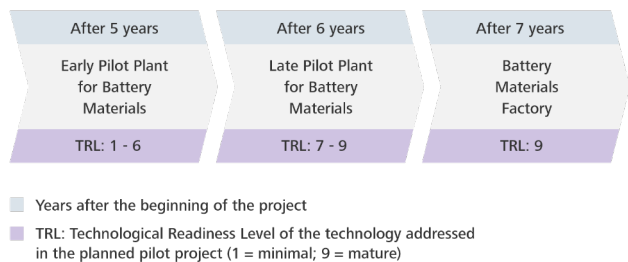


Fig. 4.11: Timeline and TRL for the installations envisioned by the battery materials subgroup

4.7.1 Summary

In this feasibility study, the Green-Batteries competence group suggests possible installations related to battery material production, 2nd-life applications, and battery recycling. As has been shown previously, these installations are capable of reducing greenhouse gas emissions related to battery production, are invaluable for gaining more independence from the material supply chain, and play a crucial role in implementing a circular economy of batteries.

It has been proven that the Fessenheim region is very well suited for the realisation of the proposed installations because of the available infrastructure as well as the battery-connected expertise that is already available through universities and research institutes.

Additionally, jobs that are connected with this industry will be future-proof, since there are not many alternatives to batteries when it comes to electromobility.

The biggest challenge for the implementation of pilot ideas is convincing companies to build their facilities in the region; therefore, easy access to start-up funding schemes, cheap energy from RES, and area provision for the proposed facilities are essential.

4.7.2 Recommendations

We recommend following the holistic approach described in this feasibility study by implementing as many of the suggested facilities from the different competence groups (batteries, hydrogen and smart grid) as possible. Regarding the circular economy approach for batteries described in this report, it is crucial to have a variety of installations that deal with battery materials, 2nd-life utilisation and battery recycling. These facilities can not only profit from each other, but also provide the advantage of reduced transportation distances.

We recommend an integrated concept “Circular Economy for Battery Electric Storage Systems and Electromobility” in the battery field. This concept can create huge economical opportunities for the region of the Upper Rhine valley in a booming battery market and includes a highly innovative dismantling and recycling plant and a utility-scale hybrid energy storage.

Implementation of a dismantling and recycling plant requires highly efficient infrastructure logistics for transportation and collection of used batteries, that are for example sourced from the exponentially growing electromobility market. Besides well-developed rail and road systems, the Rhine and its ports located in the Upper Rhine valley, particularly Fessenheim and Breisach, support an integrated cost-efficient approach. This concept is accompanied with a qualification station for used batteries and a second-life approach.

In this context, the EURO district Breisach/Biessheim seems to be able to provide space in its industrial zone because of its proximity to the local port on the Rhine and to the local train station and can contribute to creating a collection and qualification infrastructure and a test bed for dismantling and recycling pilot projects.

The electrical network of the old nuclear power plant could be ideally used for implementing a large-scale hybrid energy storage (several 100 MWh). Such storage systems are needed for the accelerated integration of fluctuating renewables (PV and Wind) to power grids. The suggested hybrid approach consists of a second-life battery block, a NAS battery, a redox-flow battery and a Carnot battery. With such storage systems, various solutions for stabilising the power grid can be addressed; from provision of short-term high power rates to buffering energy for a couple of days as a so-called long-duration energy storage¹.

Cost estimations

The integrated concept “Circular economy for Battery Electric Energy Storage Systems and Electromobility” has to be further developed. For the corresponding tasks an estimated budget of €10 Mio. for 10 people and 3 years is needed. This budget includes the coordination of three topics

- Second-life hybrid energy storage and application
- Dismantling plant
- Recycling plant

Thereby the coordination tasks include

- Engineering / technical development

- Economics / business plan development
- Regulatory framework / politics

In a first step, budget estimations have been conducted for the three topics of the integrated concept “Circular economy for Battery Electric Energy Storage Systems and Electromobility”:

- €120 Mio. for 300 MWh second-life hybrid energy storage
- €130 Mio. for dismantling and recycling pilot projects

To convince companies to build their facilities in the region, easy access to funding schemes and the provision of areas for the planned facilities are essential. The conditions for the construction of factories have to be very clear. Important considerations to be addressed by industrial stakeholders were highlighted in section 4.5.3.

See Pilot Sheets.

4.8 Interested Industry Partners

- Tech3D France
- BASF
- Opta LP
- MobEnergy
- Veolia Euro Dieuze Industrie
- Daimler
- BMW
- Peugeot
- EDF
- DHL
- Knoll
- Storion
- Hydac International GmbH (Watercooling, process water filtration)
- Knoll Feinmechanik GmbH (Automation)
- KUKA AG (Robotics)
- LCOMS
- TDF Infrastructure SAS
- BENNING CMS Technology GmbH
- Stellantis (PSA)
- ASD Automatic Storage Device GmbH
- TRICERA energy GmbH

¹ Net-zero power - Long duration energy storage for a renewable grid, www.ldescouncil.com.

- Hitachi Energy Germany AG
- Enolcon
- MAN-ES
- Bouygues Construction (F) + Kraftanlagen München (D)

4.9 Contacts

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5. Multi-Modal Green Hydrogen Hub Fessenheim

As part of the feasibility study, a concept and different lines of action for Franco-German demonstration projects for the Fessenheim Innovative Region have been developed. The overall objective is to develop a sustainable and forward-looking CO₂-neutral economic region. The transformation of society and the economy towards a renewable energy supply and a sustainable use of resources, combined with the creation of future-oriented jobs, will be strongly promoted by implementing hydrogen as an energy carrier. Green Hydrogen allows seasonal storage of renewable electricity, allows to introduce green energy in industry processes that are not yet de-fossilised by green electricity, and to make the energy system more robust by coupling the different energy sectors in a flexible and efficient way.

5.1 Background

The current consumption and supply schemes in the region provide important insights with regard to potential consumers of green hydrogen and scope for using renewable sources for its production, respectively.

The most relevant information can be found in the Trina-tional Climate and Energy Report of TRION-climate e.V. (2019) and also in the framework of the Interreg Upper Rhine project RES-TMO. The total final energy consumption in the Upper Rhine Region amounted to 38.7 MWh per capita in 2016 on average (see Fig. 5.1), which is slightly above the averages of each studied sub-region alone. 52% of the secondary energy was consumed by industry and the energy sector, 27% by residential buildings and 19% by road transport.

The region provides quite a powerful spectrum of renewable energies. In 2016 the total renewable energy production in the Upper Rhine region was 28.5 TWh with the largest contribution by hydroelectricity (56%), followed by biomass and waste (30%) and then solar heat and photovoltaic (PV) (4%). There is a strong focus on PV and wind on the German side, whereas France and Switzerland have a stronger focus on hydroelectricity. Biomass use is equally intense on the French and German side (TRION-climate e.V., 2019). For further details see Chapter 3 of this report.

2016 Final Energy Consumption per Capita (MWh/Inhabitant)

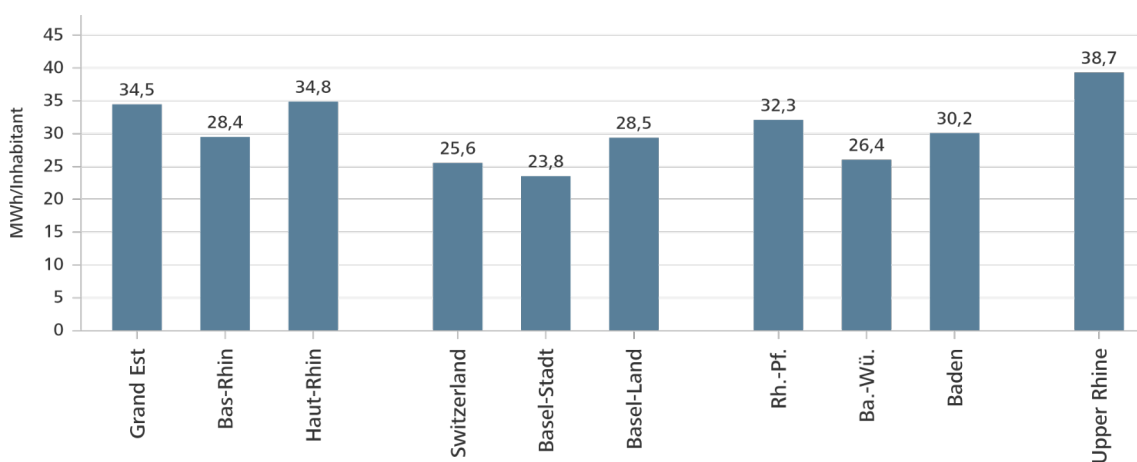


Fig. 5.1: Trinational Climate and Energy Report (TRION-climate, 2019)

5.2 Scope of the study within the competence group green hydrogen

The region is full of elements, projects and actors which may combine to form the Multi-Modal Hydrogen Hub covering the full value chain of production, distribution and usage of green hydrogen. This diversity and complementarity were revealed by the "South Rhine H₂ Summit", which was organised this November in Biesheim (Haut-Rhin) by the European Collectivity of Alsace.

Based on a set of key elements, the objective of the study was to compose the hydrogen hub in a long term vision as sketched in Fig. 5.2. The elements for production, storage and distribution as well as the usages are depicted with small buttons arranged close to the geographic implementation. The center is defined by the large scale infrastructures. This is surrounded by a more distributed scheme for production and use, mainly needed by refineries, chemical and pharmaceutical industries. The outer elements represent the wider distributed use cases, which are mainly used for heavy duty and public transport in the larger cities of the region: Freiburg, Colmar and Mulhouse. The outer block also includes the import/export interface, established mainly via transport on the river Rhine or on railways.

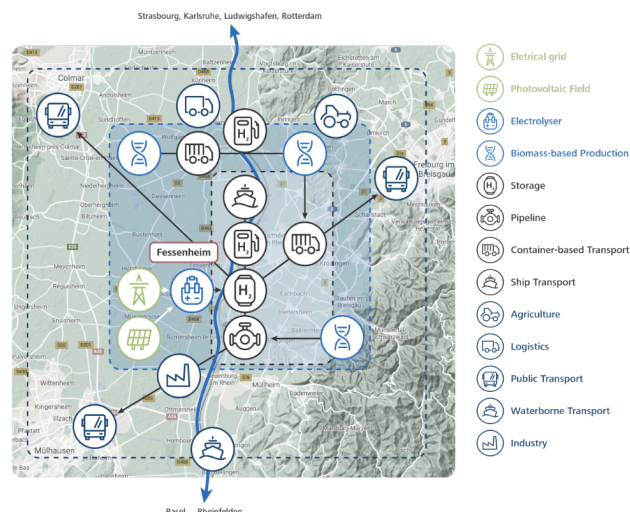


Fig. 5.2: The Multi-Modal Hydrogen Hub Fessenheim

Instead of the seemingly obvious sequence of the value chain of green hydrogen, i.e., “production - distribution - use”, the following presentation of the key elements starts with the identification of potential consumers. From these most promising use cases, the actual need for green hydrogen production is derived. The corresponding scales and schemes for production then determine associated supply infrastructures. The latter includes solutions for importing and exporting green hydrogen beyond the regional scope.

5.3 Potential Applications of Green Hydrogen in the Region of Fessenheim

Hydrogen applications start with the large-scale use in industry and continue with the more distributed applications relying on the robust infrastructure and cost reductions realised with the initial industrial applications. This sequence was determined after several consultations with potential shareholders and was supported by a demand analysis “H₂-SO – Wasserstofftechnologien am Südlichen Oberrhein” of Fraunhofer-Institut für Solare Energiesysteme ISE, funded by the BW state department (Wasserstofftechnologien am Südlichen Oberrhein H₂-SO, n.d.) and in parallel with a study carried out by the researchers of the Felis department of the University of Freiburg (FeLis, 2021).

In the EU, EFTA & the UK the total demand for hydrogen is estimated to be 8.4 MT (million tonnes) of hydrogen or 327 TWh in the year 2019 (Hydrogen Europe, 2020).

The main consumers in the industry for the year 2019:

- Refineries, which accounted for 49% of the total hydrogen use. Refineries are the largest hydrogen consumers in the EU.

- The ammonia industry, which accounted for 31% of the total hydrogen use. The ammonia industry is second to refineries when it comes to hydrogen consumption.
- Other chemical industry consumed about 13%. In the chemical industry, hydrogen is used either as a feedstock or as an intermediate product used for the production of other chemical products (Hydrogen Europe, 2020).

The three industries mentioned above are responsible for a large percentage of the hydrogen demand in the EU (about 92% of the total demand). The rest of the demand can be attributed to the following industries or processes (Hydrogen Europe, 2020):

- Steel manufacturing & metal processing
- Glass manufacturing (as an inert or protective gas)
- Food processing (for margarine production)
- Energy production (for example in CHP plants)
- Fuel cells
- Generator cooling

The transportation sector and specifically clean applications for hydrogen made up a very small share of consumption (Hydrogen Europe, 2020).

The four EU countries with the highest production capacities also make up the largest portion of the EU consumption. These countries are Germany, the Netherlands, Poland and Spain. Out of the three countries of interest, Germany is the country with the largest hydrogen consumption comprising 20% of hydrogen consumption. France and Switzerland consume much less in comparison (see Fig. 5.3).

Total Demand for Hydrogen in 2019 by Country

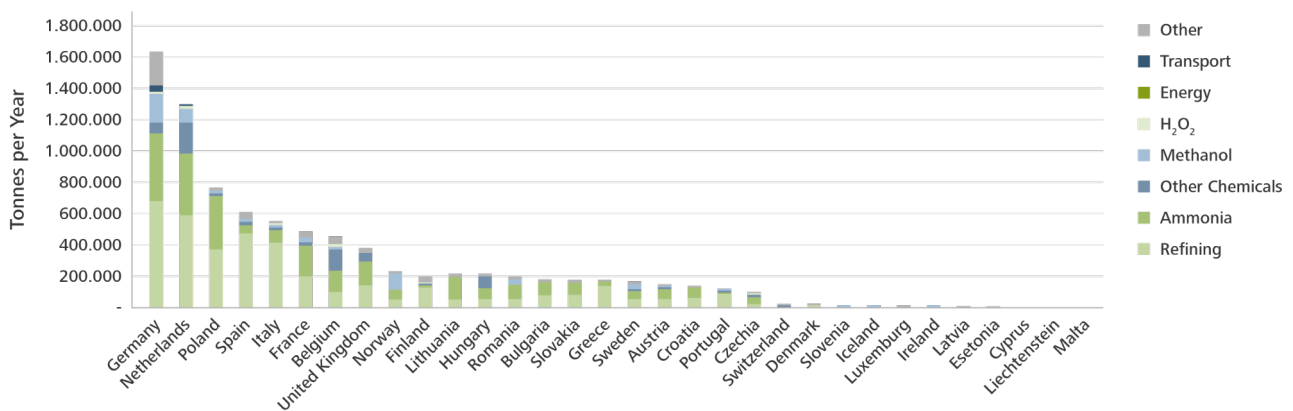


Fig. 5.3: Total demand for hydrogen in 2019 by country (Hydrogen Europe, 2020)

Based on a study by the Felis department of the University of Freiburg, two methods were used to estimate the hydrogen demand (FeLis, 2021). The first method included a questionnaire that was distributed to companies in the French and Swiss URR. The companies were chosen based on different criteria that included energy intensive manufacturing industries and industries that have a strong regional presence. Moreover, the industries included the manufacture of food and beverages, the manufacture of paper and paper products, the manufacture of basic metals, and the manufacture of non-metallic mineral products etc.

However, feedback from the companies was not sufficient to produce conclusive quantitative results despite the large number of companies contacted on both sides. Interesting information can be found in the report about the few companies that did reply.

The website *Géorisques*¹ which was used for compiling the list of companies publishes information about the different substances used by the different industrial establishments that are deemed risky. According to the website, any industrial or agricultural operation likely to create risks or cause pollution or nuisances, particularly for the safety and health of local residents, is a Classified Installation for Environmental Protection (ICPE). An ICPE is subject to numerous regulations for the prevention of environmental risks, particularly in terms of authorizations. Therefore, it was possible to filter the companies not only regionally (at the level of the department) and by industry, but also by risky substances used by the industry. The results for hydrogen and oxygen are included in the tables 5.1 and 5.2 below.

Company	Hydrogène (numéro CAS 133-74-0) (in tons)
NLMK Strasbourg	3.0
Liebherr France SAS	0.6
TEREOS STARCH & SWEET-ENERS EUROPE	3.0
Sum	6.6

Tab. 5.1: List of Companies using Hydrogen

Company	Oxygène (numéro CAS 7782-44-7) (in tons)
CLEMESSY MOTORS	1.0
LIEBHERR FRANCE SAS	22.7
ESSITY (ex TISSUE FRANCE)	2.8
Hôpitaux civils de Colmar	0.5
JET AVIATION AG BASEL	22.7
SUPERBA SAS	2.4
NOVARTIS PHARMA SAS (biotechnologie)	46.0
SAREL	9.2
SENERVAL UIOM	2.4
RAVAGO Building Solutions France	0.2
GDE METALIFER Rohrschollen	1.9
CRISTAL UNION	50.0
MERCEDES-BENZ MOL- SHEIM	6.6
LALIQUE	3.4
LES JUS DE FRUITS D'AL- SACE	4.7
Hôpitaux Universitaires de Strasbourg	51.3
LEDVANCE SASU (ex-OS- RAM)	80.0
Sum	307.9

Tab. 5.2: List of Companies using Oxygen

The second method described in the report relied on statistics to estimate the use of hydrogen by assuming that the total current industrial consumption of natural gas in the Upper Rhine Region in France and Switzerland is substituted by hydrogen and therefore constitutes the future hydrogen demand theoretically. The table 5.3 depicts the total natural gas consumption of the industry in the French and Swiss URR.

¹ <https://www.georisques.gouv.fr/>

Upper Rhine Region	Natural Gas consumed by the Manufacturing Industry (in GWh)
URR France	4,791
URR Switzerland	2,550
Sum	7,341

Tab. 5.3: Natural gas consumption in the Upper Rhine on the French and Swiss side

The natural gas consumption of the French and Swiss Upper Rhine industry was then converted to future theoretical hydrogen demand by making the following assumptions were made:

- The natural gas consumed by the industry is replaced by hydrogen as a fuel
- Energy efficiency improvements in the industry are disregarded
- Other uses of hydrogen are disregarded and considered beyond the scope of the study

The method uses gravimetric energy density of hydrogen to calculate the needed amount (in tonnes) of hydrogen to produce the same amount of energy produced by the natural gas consumed by the industry. The detailed calculations and description of the methodology are included in the aforementioned report. The theoretical and future hydrogen demand in the URR was estimated to be 218,482 tonnes per year.

It is important to mention that the statistical method is limited by the availability of publicly accessible data that may differ from country to country. For example, for the French URR, natural gas consumption is found for the year 2019 whereas for Switzerland, it is from 2018. The natural gas consumed by the industry in both countries at the URR scale also had to be estimated from more general data.

Nevertheless, this approach is an important starting point for estimating the hydrogen demand and therefore the hydrogen potential for the Upper Rhine Region.

Despite the setbacks of the questionnaire method and the low response rate from the regional industry, our observation is that a survey of the most important natural gas consuming companies of the region is important to complete the picture of the URR hydrogen demand. Strong networking with the industry and access to relevant contact information is crucial. Among the interesting observations included in the report is that in general hydrogen is a relevant topic to the industry but their knowledge about it is limited.

When it comes to the large-scale production of hydrogen, it is also important to mention that the method used for production plays a big role in how green it is. Hydrogen produced via water electrolysis (Power to Hydrogen or PtH) is promising and can be generated with little to no carbon emissions, but the feasibility of its production will depend on lowering the costs of its production through renewable energy in order to ensure that hydrogen contributes to the EU decarbonization effort in general (Hydrogen Europe, 2020).

In 2020, France alone produced about 880,000 tons of hydrogen per year, which was mainly used for desulfurization of petroleum fuels (60%), ammonia synthesis (25%) and chemistry (10%). It is not only expected that the production rate will increase to 1,345,000 tons of hydrogen until 2030, but also that the decarbonized share will increase from 5% to 52% (Observatoire de l'hydrogène Vig'hy, 2021). Combining these expectations with our estimated hydrogen demand of the industry, changing their energy source from natural gas to hydrogen, of around 218,000 tons for the Swiss and French URR alone shows how promising the hydrogen demand in the whole URR appears.

For the German side the hydrogen demand was investigated in the study of the Fraunhofer ISE 2021. The report is still unpublished, but should be available during the year 2022. Until now only a heat map is published for the hydrogen demand on the German side, this shows the hydrogen demand with high certainty today in tonnes per year.

They state a hydrogen need of more than 20 000 tons per year only on the German side. This is not yet turned into calculation for substituting natural gas by hydrogen by the research group at Fraunhofer ISE, as it was done for the Swiss side and the French side, by the research group at FeLis. These calculations still have to be carried out, but it can be assumed that this is approximately in the same range as on the French side. Another study to be published by the Umweltministerium of Baden-Württemberg estimated the yearly industry demand for green hydrogen in the state to be about 100 000 tons, based on data of the year 2020.

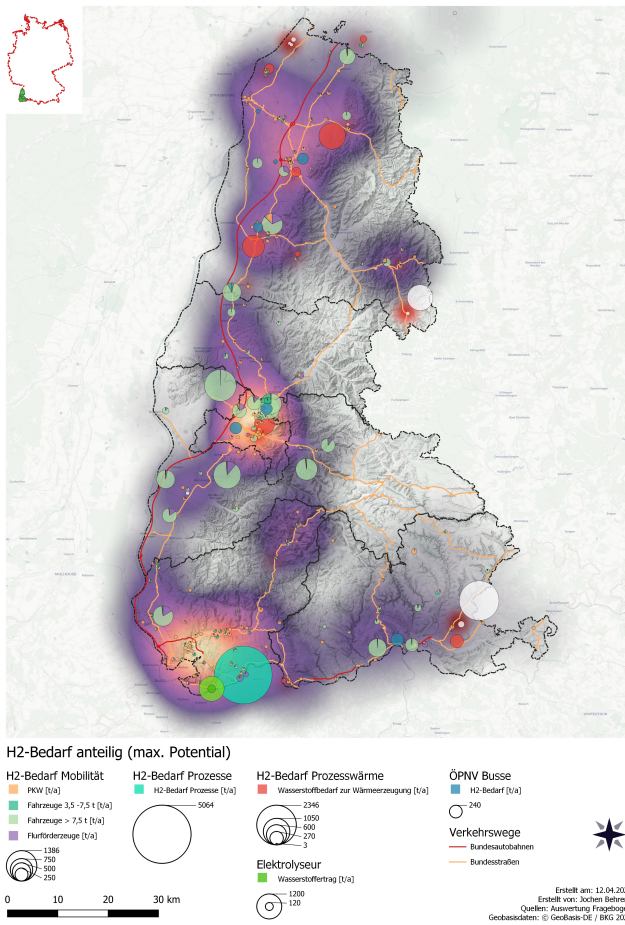


Fig. 5.4: Heat map for projected hydrogen demand on the German side as well as the list for the hydrogen use in 2021 (H₂-SO: Wasserstofftechnologien am Südlichen Oberrhein Potentialerhebung –Räumliche Analyse Klimapartner Oberrhein 2021).

Cluster	Ortenau [t/a]	Breisgau [t/a]	Dreiländereck [t/a]	Waldshut [t/a]	Σ [t/a]
PKW	204	188	79	107	578
LnF	57	368	59	8	492
SnF	810	6.268	541	903	8.522
FFz	106	315	209	94	724
Busse	237	407	0	240	884
Mobilität	1.414	7.546	888	1.352	11.200
Prozesse	0	0.1	5.000	0.8	5.001
Prozesswärme	1.320	604	0	2.616	4.540
Summe	2.734	8.150	5.888	3.969	20.741

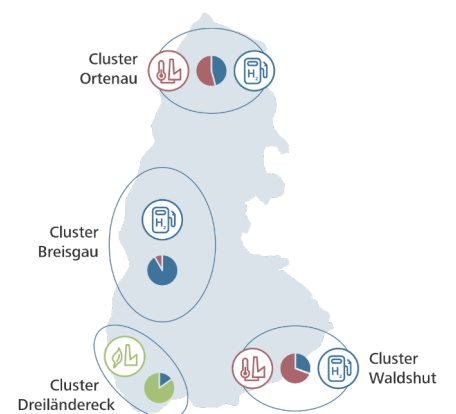


Fig. 5.5: Sectors by Cluster

5.4 Pilot Development Based on Potential Industry Use in the Upper Rhine

Currently most of the worldwide yearly produced 120 Mt hydrogen is used for chemical processes, ammonia and methanol synthesis and the refining of crude oil (IEA, 2019). Many industrial facilities are aligned along the river Rhine in Germany and along the French riverside, from Lauterbourg at the border with Germany, to the city of Saint-Louis at the corner of Switzerland and the federal state of Baden-Württemberg. Most of the industrial sites are concentrated around Strasbourg, Mulhouse, Colmar and Cernay. Benefitting from the presence of road and railway connection across the Rhine to Germany, the areas of Chalampé/Ottmarsheim/Neuenburg-am-Rhein and Neuf-Brisach/Breisach-am-Rhein also are characterised by intense industrial activities. Among all industries in the region, those having a current or potential demand for hydrogen like steel, glass, and chemical production are assessed in more detail in the following.

5.4.1 Chemical Industries

Hydrogen is an important raw material for various chemical industries: It forms the starting point for important chemical value chains that are based on ammonia or methanol and is used in large amounts for hydration and hydro-cracking processes in oil refinement. Around 12.5 billion cubic metres of hydrogen are already used in Germany every year. This makes chemical industries the largest consumers of hydrogen which is currently mainly produced from natural gas through steam reforming.

For example, BASF in Ludwigshafen produces and processes large amounts of ammonia and MiRO in Karlsruhe as one of the largest oil refineries in Germany needs significant amounts of hydrogen which is currently produced from natural gas through steam reforming. Therefore, it seems reasonable to assess the potential of hydrogen and ammonia use through chemical industries (but also regarding other potential users) in a larger regional context. In the closer region around Fessenheim, particularly Evonik Rheinfelden, BASF but also Linde France in Chalampé, which is already planning a larger electrolyzer, are promising potential users of green hydrogen or ammonia or further derivatives such as methanol. BASF has acquired a polyamide plant at the Chalampé site in France, about 10 km south of Fessenheim. With more than 10 000 t per year large quantities of hydrogen are needed. Currently this need is satisfied with hydrogen conventionally produced, generating typically 100 000 t CO₂ annually. These values are in the same order of magnitude as indicated in the H₂-SO study for the German side. The estimated costs for this “grey” hydrogen is currently in the order of 1.5 € / kg.

Evonik Industries at the Rheinfelden site produces bleaching and oxidation agents, detergent base materials, filler materials and matting agents, and silane for a very varied range of applications. Many of the initial and intermediate products from which the valuable end products are made, are produced at Rheinfelden itself. Also, hydrogen is used here, however, the specific hydrogen consumption by Evonik in Rheinfelden is not publicly available.

Finally, BASF is evaluating CO₂ capture in Ludwigshafen as a way to reduce emissions. Such captured CO₂ could be used with the region's green hydrogen for further processing (Fischer-Tropsch Synthesis, Methanol Synthesis, etc.) and then shipped across the Rhine back to Ludwigshafen or other locations.

5.4.2 Glass Production

With its high heat requirement - especially for the melting process - the glass industry is one of the most energy-intensive industries. Currently, more than 70 % of the energy is covered by fossil fuels such as natural gas, in addition, CO₂ is released due to the process of melting raw materials including carbonates. Up to 80 % of the total emissions are energy-related. With green hydrogen produced from renewable energies, the share of the resulting emissions could be reduced significantly. The use of hydrogen as a fuel in industry is, however, not yet a technical standard, which means that the effects on the very sensitive melting process in glass production, the product quality and pollutant emissions still need to be investigated. First attempts to use green hydrogen in glass production could also be the addition of hydrogen to natural gas as a fuel for the burners. Besides hydrogen, oxygen could also be directly used in glass production. Addition of oxygen in the furnaces increases the process efficiency (oxy fuel burners or oxygen heated melting furnaces) and significantly reduces further air pollutants such as NO_x or particulate matter. Besides, the product quality can be increased by directly adding oxygen in the furnace process. Hence, the combination of electrolysis to produce hydrogen and oxygen and to directly use both products in glass production is a promising solution to reduce GHG emissions from glass production. Due to the exhaust heat of the melting processes, also High Temperature Solid State Electrolysers (HT Electrolysis) that require pressurized steam but have significantly higher efficiencies (around 80% based on the LHV) compared to low temperature solutions such as PEM or Alkali Electrolysers (around 65% based on the LHV) could be used in future. The Technological Readiness Level (TRL) of around 7 for HT Electrolysis is not yet at commercial level. In the Fessenheim region, EUROGLAS S.A. in Hombourg is the most important representative of glass industries and a potential user of green hydrogen and oxygen. However, the actual demand for green hydrogen at EUROGLAS SA in Hombourg (3 km south of Ottmarsheim and 8 km south of Chalampé) is about 45 t, based on an energetic scaling and a daily glass production of 580 t².

² https://www.euroglas.com/uploads/tx_lwgtbrochures/bro_gruppe-glas-troesch_en.pdf

5.4.3 Metals and Steel Production

Around 20% of greenhouse gas emissions in Germany can be attributed to different industries (around 200 million tons of CO₂ eq/a). The largest single polluter in this sector is the energy-intensive steel and iron industry. Traditional steel production from primary sources (iron ore reduction processes) rely on blast furnaces that run on coal and cause considerable amounts of CO₂ emissions. Direct reduction through hydrogen could significantly reduce the GHG emission level of primary steel production. Liquid pig iron is no longer produced here, but a solid sponge iron that is refined into crude steel in an electric arc furnace. The direct reduction of iron ore is by no means new territory: The technology has been used purely on the basis of natural gas for a long time - especially in countries where natural gas is sufficiently and cheaply available. In this way, less CO₂ is released than in the traditional blast furnace process with coal. As BSW (Badische Stahlwerke GmbH) in the Fessenheim region only runs electric arc furnaces to produce steel from secondary sources (steel scrap), there is no real potential to use hydrogen at their production site in Kehl. This would require additional production from primary materials (iron ore) through direct reduction to iron sponge materials that could then be processed together with secondary scrap in the electric arc furnaces. However, there are indications that there is a considerable demand for oxygen by BSW to improve the process efficiencies. This could be sourced as a byproduct from a nearby electrolyzer.

5.4.4 Heavy Duty Transport

On the other hand, transportation companies have a more homogeneous geographic distribution on the territory. However, the optimization of the costs, and particularly the Total Costs of Ownership (TCO) is an important criterion for a successful development of those companies. With the rise of the taxes on fossil fuels and on motorway tolls, these companies are looking for alternatives to their conventional diesel-powered fleets of vehicles and some of them already experience the use of biogas for their trucks or electric batteries for their logistic centers. Recently also hydrogen driven, in particular fuel cell electric heavy duty trucks enter the market.

While the technical aspects of this new technology directly compete with the conventional one (large range of vehicles, refueling time, maintenance...), its current costs prevent transportation companies from considering it as an option in the short run. Nevertheless, the fuel cell electric vehicle may become competitive with the diesel vehicle from 2027 onwards, according to the study Fuel cell hydrogen trucks – Heavy Duty’s High Performance Green Solution (Ruf et al., 2020). Moreover, truck manu-

facturer Hyundai implemented in Switzerland a Pay-per-Use model³ for its customers in 2020. This model gives fixed tariffs for transport companies per km, independent from the maintenance, the driver, and the costs of hydrogen which diminishes the risks. As it was a success in Switzerland, Hyundai or another OEM might replicate this model in several European countries (France, Germany,...). It is also important to note that a significant number of Alsatian trucks drive daily to Switzerland, where the high-duty vehicle tax represents a high cost for them. Switching to a zero-emission technology is a strategic move towards the reduction of their TCO.

If those predictions are true, there will be a significant need for green hydrogen in Alsace within the next years to power the fleets of trucks of the region. Thus, it is essential to start building production and distribution infrastructures, such as electrolyzers and fueling stations to provide them with green hydrogen.

A hydrogen refueling station project is currently in development in Ottmarsheim. Developed by the company H₂V, the station will be commissioned in two years. At the beginning, about 20 kg per day will be delivered by tankers from Dunkerque and reserved for the heavy-duty vehicles, but the ambition of H₂V is to install a production facility powered by hydropower and solar capacities.

5.4.5 River Transport

The transport by barge along the Rhine is also a significant asset for the development of green hydrogen in the region. There are already some initiatives like the Rhine Hydrogen Integration Network of Excellence (RH₂INE) of the province of South Holland and the Ministry of Economy, Innovation, Digitalization and Energy of Nordrhein-Westfalen which aims to establish a hydrogen infrastructure along the river with the different actors of the market. Such an initiative could be applied between the region Grand Est and the State of Baden-Württemberg since there is also a high fluvial traffic of barges between the hubs of Strasbourg and Basel.

5.4.6 Agriculture

As investigated in the European project HyPErFarm³ - Hydrogen and Photovoltaic Electrification on Farm, hydrogen may play a central role in de-fossilisation of agriculture. This is especially interesting as agricultural units/communities might become self-supplying prosumers or even energy suppliers with a well-managed system for electricity and hydrogen, a smart grid on a small scale. This model is supported by farmers, who are typically in favour of developing their sites as self-supplied islands. However, even at a higher level, at an agricultural cooperative for instance, self-supplied schemes in particular for

³ <https://www.ise.fraunhofer.de/de/forschungsprojekte/hyperfarm.html>

fuel are well established. So, hydrogen might support the continuation of the cooperatives' business model to act as trading institutions for fuel, energy respectively for agriculture in general.

The DEUTZ Company has already developed combustion engines for the use of hydrogen in agricultural machines. Actually, the required power peaks and robustness with regard to fuel impurities are achievable by combustion engines only (e.g. in deep and muddy soil, on slopes or meadows, highly loaded trailers, etc.). Further alternatives of hydrogen use refer to the conversion of diesel engines in tractors and tractor units. The conversion of existing tractors to hydrogen (combustion over an amount of 70% hydrogen, 30% diesel) can help to decarbonise agriculture in general (e.g. Keyou, 2021). In doing so, the benefits would extend to the entire fleet and upgrade it in parts (performance enhancement). The advantage is that to the understanding of the hydrogen competence group this can be realised with low financial investments in the near future.

5.4.7. Public Transport

Public transport is a sector where green hydrogen usage is well developed and demonstrated in several European and national projects. The prices for hydrogen driven buses have considerably dropped and the industry has scaled up production capacities. In July 2019 the European clean vehicle directive (n°2019/1161) was published. It should have been transposed into a national law in every member state of the European Union on July the 2nd 2021 at the latest. This directive prompts the local communities to renew their bus fleets with cleaner vehicles.

Strasbourg currently has around 275 buses, among which 148 are already powered by biogas and 61 are electric buses. In 2024, the city will not have any diesel buses. Mulhouse has currently around 105 buses, among which 90 are diesel buses. The city wants to have 44 biogas-powered buses in 2024 and the biogas is produced by the muds of a water treatment plant. Colmar has currently 37 buses that use natural gas out of 41 buses. Nevertheless, the natural gas comes currently from fossil sources.

Regarding trains, the region Grand Est has ordered at least 3 hydrogen trains to serve the line Mulhouse- Thann-Kruth. The first tests should take place in 2023 or 2024. Additionally, the president of the departmental council of the Haut-Rhin Brigitte Klinkert is willing to reopen the line Colmar/Neuf- Brisach/Freiburg in 2026-2027 with a fuel cell powered train. Some studies are already in progress.

5.4.8 Tourism

Tourism has to also account for its CO₂ footprint. The Upper Rhine valley is a very attractive touristic destination, which combines local specialities, such as grape-growing and other touristic activities. The protected nature parks in the Vosges as well as the Black Forest contribute to the touristic appeal. The geothermal sources offer huge potential for recreational baths already used by the Romans. All these touristic activities should be embedded in a sustainable environment and hydrogen technology may help with this holistic concept. Moreover, the interested tourist may have direct contact with these new clean technologies and learn how they function.

5.4.9 Summary of Demand

Industry demand for green hydrogen is the largest in comparison to other demand types. Green hydrogen may directly replace conventionally produced hydrogen. So, the easiest and most economical way to achieve CO₂ emission reduction is by a few large investments. Linde France for instance is planning a 40 MW electrolyser on the industrial site of Chalampé to provide the surrounding industries with green hydrogen. The Communauté Européenne d'Alsace recently announced that their ambition was to have a capacity ranging from 200 MW to 300 MW of electrolysis on both sites of Chalampé and Fessenheim. They are working on a "hydrogen network" starting from Neuf-Brisach to Basel.

It is suggested to first support the introduction of green hydrogen at an industrial scale, which intrinsically reduces costs for green hydrogen production. These reduced costs will ease the introduction of more distributed use cases, e.g., heavy duty transport applications on roads and water.

5.5 Local Green Hydrogen Production

A green hydrogen hub implies that the production and consumption of green hydrogen should be co-located to the largest economical degree. However, the natural resources of the region might be limited and some pathways for production may not be acceptable due to societal or regulatory constraints, even if they are economically attractive.

Sustainable hydrogen production is based on renewable energy. The Fessenheim region possesses the best conditions for hydro and photovoltaic (PV) electricity because of the river Rhine and its solar profile, (see chapter 4). The combination of both provides the required "additionality" and capacity factors with excess electricity from PV during daytime and from hydro-electricity during the night-time. Generally hydro-electricity is more flexible and valuable as a controllable energy source compared to the more volat-

ile PV electricity. Since the social acceptability of wind turbines and geothermal energy in the Rhine valley are limited, this option is not considered further in this report, but with changing political and regulatory frameworks it might be considered in the next periods.

The strong agricultural background, however, suggests the use of biomass of the 2nd generation and waste of the agricultural processes as an additional and reliable backbone resource for producing green hydrogen. The biomass based hydrogen production might even offer CO₂ negative processes.

The potentials of hydro, biomass and PV are described in detail in the study of the Atmo-VISION and RES-TMO report 2022 (Najjar et al., 2022), of which certain parts are integrated in this report.

5.5.1. Electrolysis

The analysis of the non-industrial demand side of the region assuming refueling for 100 buses, 25 heavy duty trucks, 2 trains and 2 ship would require 7.5 t on a daily basis (and 2800 t per year) corresponding to a 20 MW electrolysis operated for at least 7000 h per year (80% capacity factor). The electrolysis should be located closest to the highest hydrogen demand, as electricity transport is cheaper compared to hydrogen transport. Consequently, ship refueling will be placed close to the existing harbor infrastructure in Fessenheim or other Rhine harbours nearby. Furthermore, the grid infrastructure at the former nuclear site is deemed the best suited for collecting distributed PV electricity. Therefore, it is suggested to place the electrolysis farm close to the hydropower plants of Fessenheim or Ottmarsheim.

5.5.2 Hydroelectricity

The costs of hydrogen produced by electrolysis are reduced with increasing electrolyser capacity, and is directly related to the price of electricity. Therefore, it is proposed to use the electricity produced by the existing hydropower plants of the region as far as possible from regulatory and contractual aspects.

The power station of Fessenheim in the picture above is historically built on the Grand Canal d'Alsace and it began producing electricity in 1956. With a nominal power of 176 MW generated by four Kaplan turbines it is the most powerful of the 10 hydroelectric plants on the Rhine. This is correlated with a fall of 15.7 metres. Its yearly production of electric energy amounts to 1020 GWh, corresponding to 5800 full load hours or a capacity factor of 66%. It was, right from the start, designed to be more automated than Kembs and Ottmarsheim, which are also potential hydropower plants for scaling up the regional



Fig. 5.6: Fessenheim hydroelectric power station

production of green hydrogen.

5.5.3 PV electricity

Existing rooftop installations could be integrated in the central PV electricity harvesting for Fessenheim. Solar PV could also be installed in the vicinity of the power plants to provide higher stability.

One possibility would be to add a floating solar panel on the basins upstream from the hydropower plant. During the day, when there is a high demand and pressure on the grid, the floating solar system could provide the electrolyser with electricity, while at night, the hydropower plant could take over the energy supply for hydrogen production. Thus, switching between the two renewable electricity sources helps to reduce the costs of production of green hydrogen. As Fessenheim is surrounded by numerous pit lakes within a few kilometers, in Germany and in France there is a considerable potential for scaling up this solution.



Fig. 5.7: Example of floating PV (1.5 MW electric peak power) plant in Leimersheim near the Rhine

Other PV installation variants could be PV along highways, e.g. integrated in the noise barriers of the A5 on the German side, or installed on airport Sonderlandeplatz Bremgarten (EDTG) only 2 km in the east of Fessenheim.

Finally, AGRO-PV would represent a scalable solution specifically adapted to the profile of the region (see Google Earth for agricultural field dimension). This might be an advantage for farmers because their fields can be better protected against direct sun during dry and hot seasons exacerbated by climate change. Also they can protect their harvest better against heavy storms and hail and finally, they can generate additional income. The AGRO-PV design can be adapted to the needs of the agricultural economy and natural environment.



Fig. 5.8: The AGRO-PV plant in Heggelbach on Lake Constance (Fraunhofer ISE, 2016)

5.5.4 Biomass Based Green Hydrogen Production

In the context of renewable hydrogen production, prioritizing biomass is a promising approach, particularly when the unvalorised agricultural bio waste can be used. Several approaches exist, relying on different processes:

- Thermochemical processes – such as gasification processes, pyrolysis, or aqueous phase reforming – are the most advanced and thus most industrially relevant technologies. They often require harsh conditions (high temperature and pressure) and the presence of a catalyst; but lead to high yield in hydrogen production (Jade et al., 2020).
- Biological conversion processes – such as dark fermentation, biological water gas shift and photofermentation – require a lot less energy to occur (temperatures 30-60°, atmospheric pressure). Nevertheless, their level of development is a lot lower (TRLs typically 3-4), the production yields and imple-

mentation scale are limited to laboratory proof of concepts (Jade et al., 2020).

- Electrochemical conversions – such as electroforming applied to biomass (also known as biomass electrolysis) or microbial electrolysis cells (MEC) – rely on implementing a bio-electrochemical system where the microorganisms act as catalysts to the hydrogen production reaction. These processes are also at low TRLs, and limited in scale, but pilot-scale implementations of MEC technologies have been reported (Jade et al., 2020).

At the University of Strasbourg, the RePSeM group led by Prof. Barbara Ernst is focusing their efforts on exploring new ways to utilize biowaste through Dark Fermentation (DF), with a particular focus on wine-waste. DF relies on engineering anaerobic microbial communities to produce hydrogen. DF offers better theoretical yields compared to other biological processes, and can be implemented in batches or continuously. Moreover, the process requires very little energy input: to make it fully renewable, we could envision a solar- or wind-powered DF plant. Nevertheless, DF is still considered a relatively low energy efficiency process (with 33% theoretical yield and 21% experimental yield observed on average). Moreover, the scale faces a limit, as most processes are implemented on a 1L reactor volume. Finally, DF co-produces biogenic CO₂ – that can be easily trapped in a membrane reactor (Galkina & Vasyutina, 2018).

In the context of a multimodal H₂ hub and considering the scale and efficiency limits DF is facing, it is a relevant technology but with low TRL level. Nevertheless, efforts are currently being pursued to overcome the technological barriers that limit a large-scale implementation of DF.

Recently, more advanced TRL projects have begun in the Upper Rhine region. The project R-HYNOCA is led by Strasbourg energy company R-ENR, with Haffner Energy, Eifhytec, and McPhy. The project aims to install a hydrogen service station in the city of Strasbourg, to power cars. The particularity of this project is that the hydrogen is produced on-site, by compressing wood-waste resulting from forestry activities. The pilot's construction started in February 2021 with the aim of being completed (and of starting the production of hydrogen) in 2023. However, it has to be stated that energetic use of wood waste might not be the future for this valuable material for bio-economy (Maack, 2018).

Initial discussions with German agricultural cooperatives have generated strong interest in promoting hydrogen as a new energy carrier and developing agricultural enterprises into producers and consumers of this green energy.

5.6. Supply Infrastructure, Import & Export Capacities

Similar to the production, the transport, distribution and storage solutions must cope with the actual local needs. Additionally, it has to bridge the points and times of production and consumption in a suitable way.

5.6.1 Hydrogen Storage

Hydrogen may be stored as a pressurized gas, liquefied or in solid storage materials, typically metal hydrides. Compressed hydrogen storage, providing a hydrogen density of about 15 g/l at 20 MPa, has the highest maturity and technologies, including compressors, are available on the market. Large scale storage with compressed hydrogen may be realized in caverns (RES-TMO report, 2022) and in underground pipe systems, similar as for natural gas. Some developments for innovative compression technology are on the way, like electrochemical compression or thermal compression combined with absorbers.

Cryogenic liquid hydrogen LH_2 provides a density of 70 g/l at 20 K and ambient pressure, which is even higher than that of compressed hydrogen at 70 MPa (about 40 g/l). Therefore, it is the preferred way to store and distribute hydrogen at a larger scale and on longer distances. Its low system weight makes LH_2 the most attractive option for weight critical mobility/transport applications with a high energy demand, in particular aviation but also long-haul heavy duty trucks. LH_2 provides implicitly highest purity and therefore is also a good choice for relatively impurity sensitive low temperature fuel cells. Currently, there are only 3 hydrogen liquefaction plants in Europe with a typical daily liquefaction capacity of 1-5 t. All three sites (Rotterdam/Air Products, Leuna/Linde, Sassenage/Air Liquide) are far away from the Fessenheim region.

Solid storage systems are the heaviest hydrogen but the most compact storage option. They are typically operated at ambient temperature and moderate pressure. Classical metal hydrides are using Fe-Ti alloys for storing hydrogen; other materials considered are light metal alloys like boronate or allanates or Metal Organic Frameworks (MOFs). The light metal hydrides, however, need a very sophisticated thermal management system for exothermic charging and endothermic release of hydrogen. Nonetheless, the required heat transfers might be integrated in the sector coupling of the energy system.

For the initial phase compressed hydrogen storage in a buried pipe storage system similar to the one shown in Fig. 5.9 is suggested. This system allows to buffer and equilibrate the hydrogen supply via injection into the gas

grid or a dedicated pipeline. Furthermore, a co-located large scale user will benefit from this buffer function allowing to run processes continuously. Additionally, this storage might even serve as a small seasonal storage device.

In the later phase a liquefaction plant (5 t/d) eventually



Fig. 5.9: Natural gas tubular storage Urdorf (Jauslin Stebler AG⁴)

combined with a hybrid LIQHYSMES storage is suggested. The LIQHYSMES, developed at the institute ITES of KIT, storage provides a Superconducting Magnetic Energy Storage (SMES) for fast electricity storage performance. The SMES is cooled by liquid hydrogen providing large energy storage capacities. The LH_2 storage implicitly provides best suited interfaces for large scale import and export of green hydrogen. Additionally, LH_2 will provide the best basis for supplying large fleet refueling stations for trucks, trains or even aircrafts (Basel Mulhouse) in the region. In addition geological storage capacities have been investigated under the project RES-TMO.

5.6.2 Injection into the Gas Grid

In coherence with the European Hydrogen Backbone initiative, led by a group of European gas operators to design a cross-border gas pipeline grid (30,000 km to 40,000 km by 2050), the Upper Rhine region between three European countries is a strategic place for the injection of green hydrogen. The conversion of the current natural gas pipeline as well as the construction of hydrogen pipes are both planned.

⁴ <https://www.jauslinstebler.ch/VGA/VEM/projekte/erdgas-roehrenspeicher-urdorf.html>

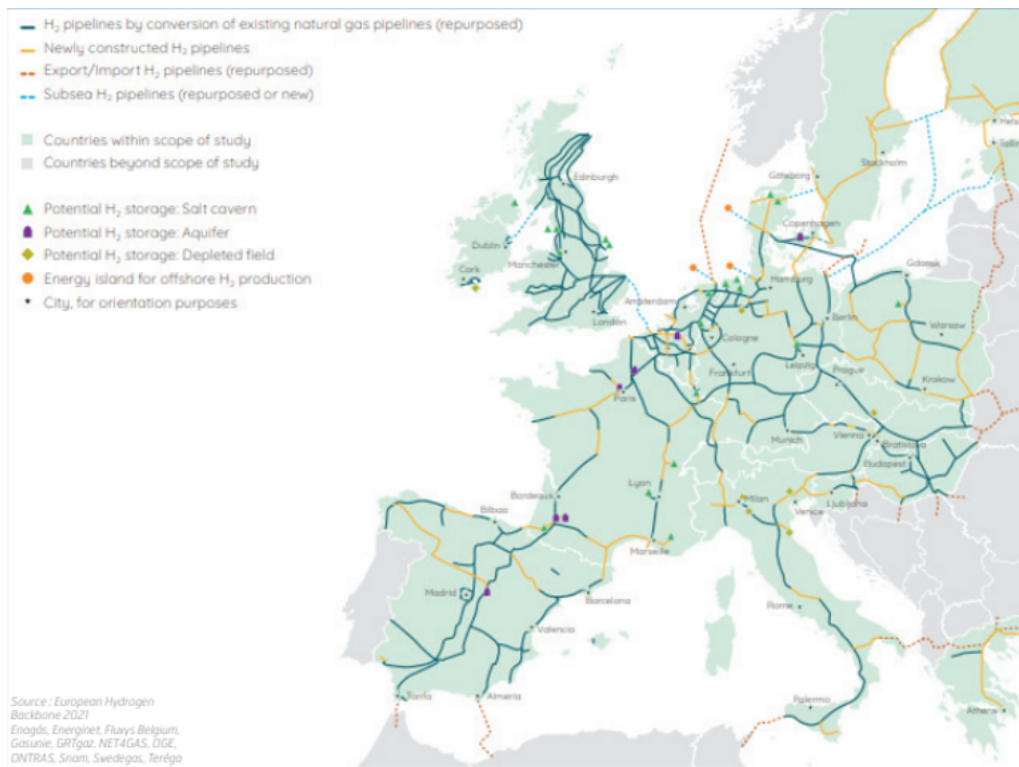


Fig. 5.10: Planned European Hydrogen Backbone⁵ (Guidehouse, 2020)

In this illustration (fig. 5.10), one pipeline on each side of the Upper Rhine is foreseen for the transport of hydrogen.

A pipeline exclusively dedicated to hydrogen transport already exists and connects the site Linde in Chalampé to its customers Butachimie, EUROGLAS, etc.

5.6.3 High Pressure Pipeline

The extension of the existing hydrogen pipeline could be realized with a high-pressure pipeline operated at a pressure of about 100 MPa. Shorter distances between the production site, i.e. the large production electrolyser and a customer with high demand especially for high pressure hydrogen, hydrogen fueling stations for large bus or truck fleet, may be economically bridged by such a pipeline. The high pressure allows for small relatively safe cross sections and might simultaneously turn the pipeline into as an intermediate storage. A prototypical installation may be found at the Infraserv industrial park in Frankfurt Höchst.

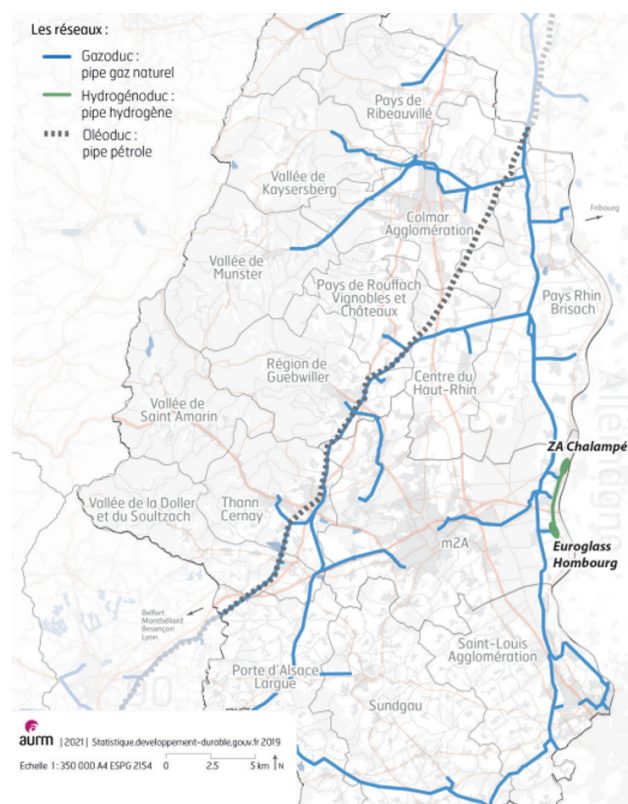


Fig. 5.11: Gas and petrol pipelines in the Mulhouse area (AURM, 2021⁶).

⁵ <https://gasforclimate2050.eu/ehb/>

⁶ <https://www.aurm.org/uploads/media/6124b2f9011eb.pdf>

5.7 Pilot Projects

The implementation of the multi-modal hydrogen hub Fessenheim comprises 4 proposals for pilot projects composed of the most important key elements presented above. In the sequence of their realization these are:

- Pilot Project H₂-A “Large scale industry supply with green hydrogen”
- Pilot Project H₂-B “Virtual pipeline”
- Pilot Project H₂-C “Heavy Duty Transport”
- Pilot Project H₂-D “Distributed production and use in agriculture”

So, the projects show an early establishment of scales necessary for the economy accompanied by an increasing involvement of the public. The figure 5.12 visualizes the interconnections between the different pilots.

Chalampé region additionally offer unique opportunities for high quality renewable electricity, which allows the use of the production path of green hydrogen via electrolysis.

Thus, the hydrogen produced with locally generated renewable electricity could find immediate lead customers with BASF, Borealis in Chalampé and EUROGLAS in Hombourg. They are all connected to the regional hydrogen pipeline. The huge industry demand, in the order of several 10 000 tons per year, correspondingly requires large scale production plants like industry-scaled electrolyser systems as shown in figure 5.13. The mass of hydrogen m_{H_2} produced in time t via electrolysis can be estimated using the following equation:

$$m_{H_2} = \eta \frac{P}{H_u} t$$

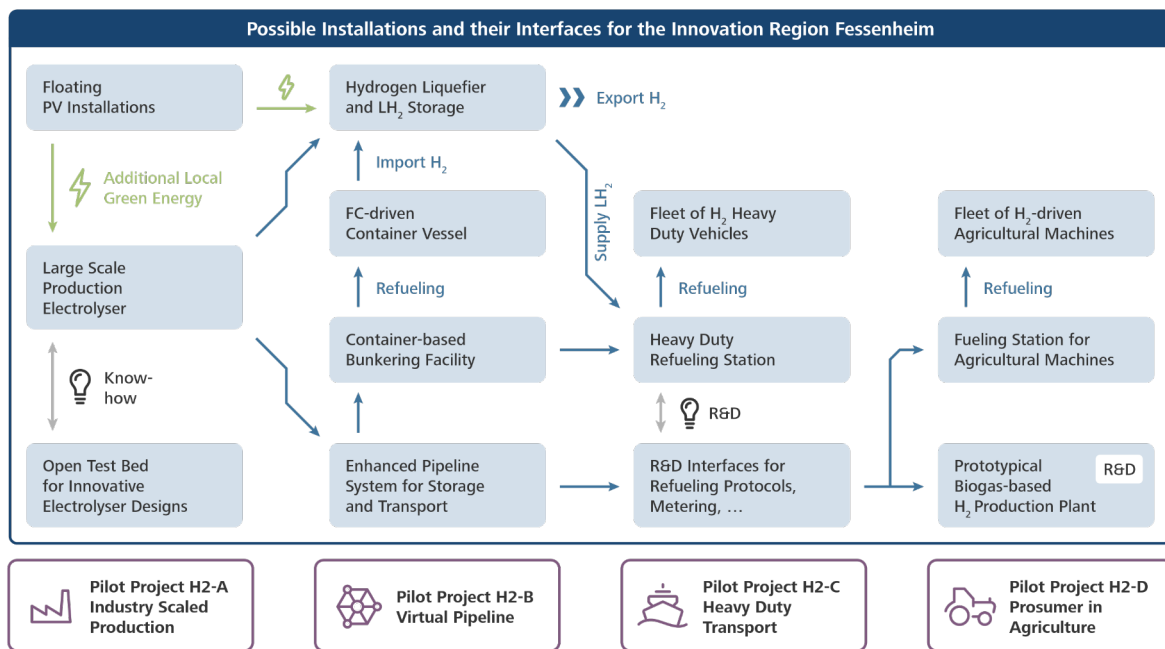


Fig. 5.12: Interrelations between the hydrogen pilots

Although they relate to each other in a complementary way, they might be realized independently as well.

5.7.1 Pilot Project H₂-A “Large scale industry supply with green hydrogen”

Replacing conventionally produced hydrogen for large industry applications represents a large existing market for green hydrogen. Strong effects in CO₂ reduction could be achieved on the large scale at relatively low specific costs, as also existing infrastructures for distribution and storage might be re-used. The Fessenheim and in particular

with η as efficiency, P as the electric power of the electrolyser and the upper heating value of hydrogen $H_u=40$ kWh/kg. With a capacity factor of 60%, i.e. about 5000 full load hours annually, an 80% efficient electrolyser with a nominal electric power input of 1 MW will produce about 100 t of hydrogen per year.

The potential demand of the mentioned companies amounts to several 10 000 tons per year. Consequently, the electrolysis plant envisioned will be in the order of several 100 MW electric with a capacity factor of about 60-70%.

The actual operator would be either a classical industry gas supplier like Linde France or a company closer to the electricity sector (EdF/Hynamics). The renewable electricity ideally would be generated in a combination of hydroelectric power, mainly for night time and cloudy days and floating PV as an additional renewable electricity source with limited capacity (typically 1000 h/a) at daytime. This is the only way to achieve the high capacity factors required for economic viability and the additionality characteristics.

The hydroelectric power stations at Kembs, Fessenheim and Ottmarsheim provide nominally 500 MW electrical power with a capacity factor of ~ 60%, very close to the required value even without additional photovoltaic installations. The access to this hydroelectricity, however, with the established supply infrastructure and long-term contracts in place would conflict with business models of EdF, the current operator of the concerned hydroelectric power stations. Another critical aspect is the regulatory framework, which may or may not acknowledge those renewable electricity sources as “green” sources eligible for public funding. Current regulation, at least on the German side, would not allow the production of “green” hydrogen with existing hydroelectric power. Additionality and co-location of the green electricity and hydrogen production are required for being eligible for public funding in European and partially in national, French and German regulation.

The investment costs for an alkaline electrolyser of this size amount to approx. 1 M€/MW excluding product gas purification, pressurization and storage. For PEM electrolysers a surcharge of approximately 20% must be calculated. The lower investment costs and the wider experience make alkaline technology the preferred choice at least in the initial phase. However, the cost of electrically produced green hydrogen is driven by the price of green electricity. Therefore it is still significantly higher (~5 €/kg) than grey hydrogen (currently ~1.5 €/kg). So, public support and deduction of grid fees are absolutely necessary to lower green hydrogen costs. A CO₂ emission price of 200 €/t might further help making green hydrogen competitive.



Fig. 5.13: Typical large scale electrolyser set-up (Thyssen-Krupp⁷)

5.7.1.1 Electrolyser Set-up and electricity supply

It is suggested to start with a 30-40 MW initial installation. In a second step, this could be extended with additional electrolyser units to achieve the needed amount for industry. The Communauté Européenne d’Alsace announced recently that their ambition was to have a capacity ranging from 200 MW to 300 MW of electrolysis on both sites of Chalampé and Fessenheim. They are working on a “hydrogen network” starting from Neuf-Brisach to Basel.

The large scale electrolysis should be positioned closest to the large scale user and/or connected to the existing pipeline described above.

For the initial phase, one of the four turbines of the Ottmarsheim power stations should be reserved for electrolysis. For the later phase, additional power from the Ottmarsheim station and from Kembs and Fessenheim should be secured.

For the floating PV, it is suggested that EdF builds a 20 MW in the basin of the Ottmarsheim hydroelectric power plant in the first half of the project. This reduces interfaces with other potential electricity suppliers. Investment costs will be less than 20 Mio Euro. In the second phase this power shall be doubled by acquiring space on the Rumerheim Ochsengrund and the Kiesgrube Neuenburg-Grießheim. However, for the latter, a dedicated electricity transfer line has to be planned.

⁷ https://ucpcdn.thyssenkrupp.com/_binary/UCPthyssenkruppBAISUhdeChlorineEngineers/en/products/water-electrolysis-hydrogen-production/alkaline-water-electrolysis/link-thyssenkrupp_Hydrogen_Water_Electrolysis_and_green_chemicals.pdf

5.7.1.2 Additional Features, and opportunities

The Belgian group John Cockerill is building a H₂ Gigafactory for electrolyzers in Aspach-Michelbach, about 30 km away from Ottmarsheim. So, there is a highly interesting opportunity to establish a test bed for electrolyzers in combination with the large scale production electrolysis plant. The test bed for innovative electrolyser designs and grid integration strategies also interfaces with the smart grid competence group. The testing capacity might be initially co-funded by the EC by offering services via an Open Innovation Test Bed model.

The economy the electrolyser operations shall be improved by marketing the side product oxygen (typically used in medical applications, waste water treatment and steel, glass and chemical industry) and by combined use of the off-heat.

Besides, Linde France- the EdF subsidiary Hynamics has declared interest in operating the electrolyzers and caring for the electricity supply.

The industry supply with green hydrogen may be complemented, diversified and strengthened by large-scale import via the river Rhine. LH₂ is the intrinsically cleanest option for hydrogen transport and offers many other opportunities in using the low temperature, in particular for efficient electricity transport. A liquid hydrogen LH₂ landing point for bunkering, loading and deloading LH₂ with a large scale stationary cryostat is proposed for the later phase of the project in a separate Pilot Project H₂_B (Fig. 5.14). The local availability of LH₂ is a key feature for pilot project H₂C.

As a contingency plan, importing green energy via green ammonia could be another option. This is supported by a pilot project of Air Products and the Miro refinery in Karlsruhe, where ammonia will be tested as a hydrogen carrier. According to an ESYS study (to be published) ammonia is the cheapest option for long distance transport of green hydrogen, which is, however, only suitable for industrial applications with access to low-cost heat and can cope with relatively low purities of the hydrogen. Fessenheim could line up with the Karlsruhe and form an "extension" of this project.

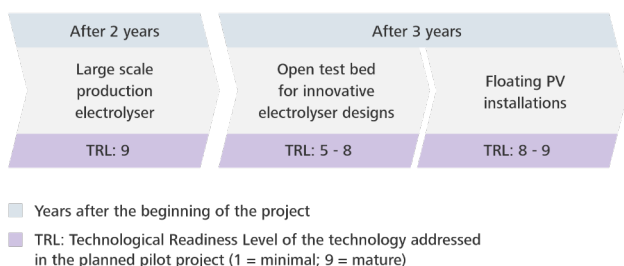


Fig. 5.14: Timeline and TRL for pilot project H₂_A "Industry scaled supply with green hydrogen"

5.7.2 Project H₂_B "Virtual Pipeline"

Currently, it is estimated for Baden-Württemberg that only a fraction of the locally required green hydrogen may be produced with local green resources. Similar limits are supposed for the Grand-Est region. For supplying the larger remaining part, a pipeline transport of green hydrogen from southern Europe for instance would be economically attractive, but the actual implementation will take considerable time. According to the European Hydrogen Backbone report only after the year 2040, the Upper Rhine area might be reached by a hydrogen transmission pipeline for providing the region with larger amounts of green hydrogen. Pipelines represent still huge investments and are in general not a very flexible technology.

Bridging the existing need for the import of green hydrogen to satisfy the larger demands at reasonable costs in the intermediate terms an efficient and scalable batch transport on the river Rhine is suggested. It will compensate the deficiency in supply by aligning the Fessenheim region with many other large industrial demand sites along the river Rhine (Cologne, Ludwigshafen, Karlsruhe,...) and by connecting it with Rotterdam, the central European landing site for LH₂. Currently, Air Products operates one out of the three main liquefiers in Europe.

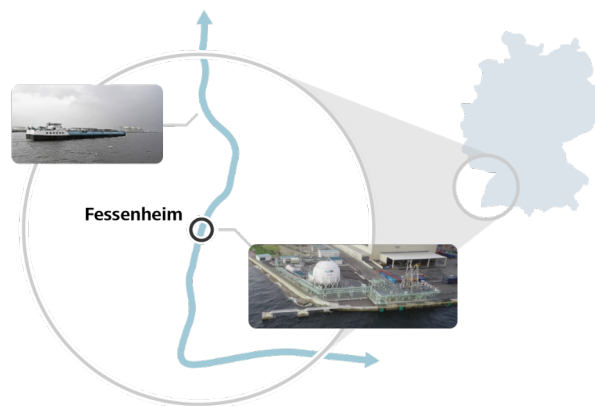


Fig. 5.15: Virtual pipeline for importing and transporting green H₂ in the upper Rhine region

5.7.2.1 Containers for multi-modal transport

The transport of hydrogen on a national, down to regional scope without the massive investment in a dedicated new hydrogen pipeline may be realized with a standardised (ISO) container solution. The container-based batch transport opens the door for multi-modal transport, which flexibly combines water, rails and street transport. The suggested solution avoids losses caused by transfer between stationary and transport containers and allows for seamless upgrading from high pressure gaseous hydrogen to more dense liquid hydrogen (LH₂). With LH₂ the capacity might be easily increased by factor 10.



Key Technical Data	
Frame Size	40ft Container
Design	UN Portable Tank
Design Pressure	12 bar(g)
LH ₂ capacity	3,000 kg (5% ullage)
Option	LIN-Shield

Fig. 5.16 : Hylics UN portable LH₂ tank (Linde⁸)

5.7.2.2 Actual transport of the H₂ containers on river Rhine

The ISO container might be directly transported on any conventional container ship. Ideally, those container vessels should be hydrogen fuelled. The strait and less capital intensive pathway suggested is the retrofitting of existing conventional container vessels as realized by Holland Shipyards Group (HSG) for Future Proof Shipping (FPS)⁹ see figure 5.17.



Fig. 5.17 : Hydrogen fuel cell hybrid electric container ship by Holland Shipyards Group (cf. VPO)

MTU has developed suitable drive-trains on fuel-cell technology basis. For the long-term solution the design of a reference vessel could then follow this of Portliner, presented by the Dutch Van Meejen Group in 2019.

Alternatively, LH₂ carriers could resemble those currently used for LNG transport. For example, BASF developed a new ship design together with a consortium consisting of the Duisburg Development Center for Ship Technology and Transport Systems e.V. (DST), Technolog Services GmbH and Agnos Consulting, who specialize in various aspects of shipbuilding. For the subsequent detailed development, BASF was able to win over the shipping company Stolt Tankers, which contributed its expertise to the project and will build the ship and operate it exclusively for BASF. On behalf of Stolt Tankers, Mercurius Shipping Group will be responsible for building the vessel. Commissioning is scheduled for the end of 2022 (Fig. 5.18).

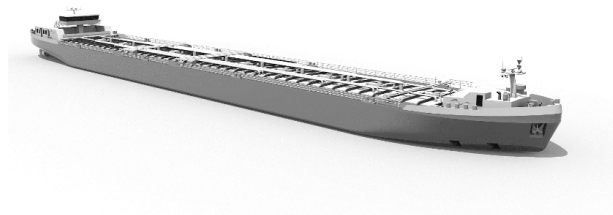


Fig. 5.18: Modern LNG vessel (BASF)

The vessel provides unique shallow water capabilities and a hybrid Diesel-electric drivetrain, where the genset might be easily replaced by a fuel cell system. However, the flexibility of a container-based solution would be lost and a smooth scale dependent transition from compressed gaseous to liquid hydrogen transport would become more difficult.

5.7.2.3 Hydrogen Fuel Bunkering

For the hydrogen-driven container vessel, a refueling infrastructure is required. The fuel supply for this ship will be based on swappable containers. Bunkering with hydrogen should be possible at Ottmarsheim and downstreams in Karlsruhe. The distance between these bunkering sites seems to be economically reasonable. Moreover, bunkering facilities might develop further downstreams, in Ludwigshafen for instance. Finally, the whole river Rhine should have sufficient fueling points that follow the identical standards to allow for a seamless water-borne transport based on hydrogen on this central European north-south transport pathway. AirLiquide will provide a solution for such a container-based fuel supply, which was already tested in a Belgium harbor. MTU has indicated in-

⁸ <https://www.linde-engineering.com/en/plant-components/helium-storage-un-portable-tanks/index.html>

⁹ <https://hydrogen-central.com/holland-shipyards-group-future-proof-shipment-maas-vessel-hydrogen-power/>

terest in providing technologies for all kinds of green harbor equipment and to become a technology provider for hydrogen fuel cell driven transport vessels. For the bunkering of a larger liquid storage container, a stationary cryostat will be required. In the beginning, this storage will mainly serve as a receiver of LH₂ delivered. Pressurization and vaporization for filling pressure vessels or feeding the existing gas pipeline will be very economically available.

5.7.2.4 Future options

Additionally, the high-quality cooling capacity with LH₂ could be used to make some key superconducting electrical equipment. A combination of the LH₂ storage with a superconducting magnetic energy storage (SMES) could open highly attractive opportunities for hybrid energy storage with a close link to the envisaged smart grid solutions. A small hydrogen liquefier with an initial capacity of 1t/d would store and initialize trading of excessive green energy /hydrogen of the region. So, the region might develop into a central trading point for the wider region of southern Germany, eastern France and northern Switzerland (see Fig. 5.19).

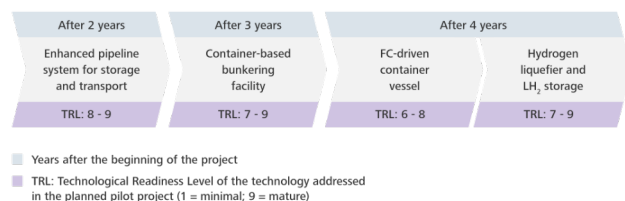


Fig. 5.19: Timeline and TRL for pilot project H₂-B "Virtual Pipeline"

5.7.3 Pilot Project H₂-C "Heavy Duty Transport"

The CO₂ reduction required by European regulation will induce the introduction of hydrogen as a fuel for heavy duty transport especially for long distance and demanding services. The infrastructural important location of the southern Fessenheim region, i.e. Ottmarsheim, connecting Northern Switzerland, Grande-Est of France with the South-West of Germany has led to many transport companies to operate branches in this area. Tax law specifics in Switzerland have already allowed an industry-led consortium to commercially operate a fleet of Hyundai fuel cell trucks. The Fessenheim region could be developed as a strategic extension of this project or independently.

5.7.3.1 Supply Infrastructure

The heavy duty transport has to rely on a capable fueling infrastructure, which should be close to the large production or the transport elements described in the pilot projects H₂-A and H₂-B above. A truck with a daily mileage of 1000 km will need 100 kg/day of fuel. A station shall be

able to supply fuel to a minimum number of 10 trucks and should be able to serve 40 trucks and a bus fleet of ~20 buses, amounting to 5 tons/day. As heavy duty fueling implies these capacities in the order of tons/day the advantage of a liquid based fueling infrastructure are obvious.

Transport, compression and pre-conditioning requirements are almost prohibitive for the gaseous pathway on a large scale. Fig. 5.20 compares the supply of a fueling station with 4 tons of hydrogen either with gas trailers or with a LH₂ trailer.

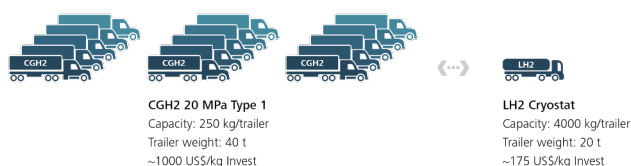


Fig. 5.20: Comparison of hydrogen batch transport variants for 4 t hydrogen; either with trailers for compressed gaseous hydrogen (left) or liquid hydrogen (right)

Moreover, a liquid-based hydrogen station offers widest flexibility for fueling compressed gaseous hydrogen, cryo-compressed hydrogen or liquid hydrogen. The latter will be practically impossible for a gas-based installation. These obvious advantages of liquid hydrogen in the scaling-up have led Daimler Truck to choose LH₂ as the onboard storage option for their GenH₂ hydrogen fuel cell truck, which might be entering the market 2027.

Besides the commercial function the fueling station should also serve for the further development and standardisation of the associated technologies. A modular concept should allow testing of critical components (e.g. high pressure coolers, vaporisers, compressors etc.), fueling protocols and of associated measurement techniques (e.g. mass flow, dispensed mass, safety critical parameters, etc.) .

The actual placing should account for the accessibility (highway connection), connection to the large-scale chemical industry supply and for any synergies with ship and/or train transport, wherever applicable, thus commonly labeled as multi-modal.

5.7.3.2 Building the fleet

There are currently a few companies preparing to enter the market with hydrogen fuel cell or ICE driven trucks (Hyundai, Daimler/Volvo, IVECO/Nicola, Toyota etc.). The only company with a larger number in the market is currently Hyundai with their XCIENT trucks.



Fig. 5.21: left: XCIENT fuel cell truck (Hyundai); right: GenH₂ with LH₂ tanks of Daimler Trucks (Daimler Trucks)

Daimler Truck already indicated a principle interest to participate and to deliver a considerable number of their GenH₂ trucks to a Fessenheim/Ottmarsheim project.

As it will be easier to negotiate the purchase and organize the operations of a larger number of trucks than to leave the development of the business case to several companies it is suggested to apply a similar concept as for the Swiss Hyundai Hydrogen Mobility (HHM) project, where a central service company manages the fueling station and the fleet of trucks and offers transport capacities to the interested logistics companies on a pay per use basis.

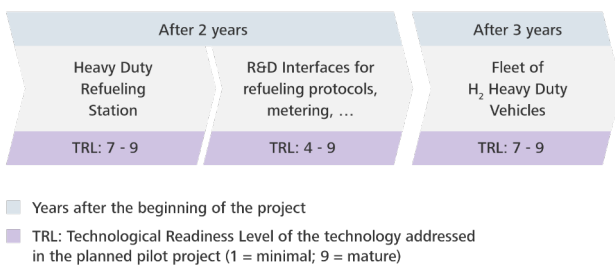


Fig. 5.22: Timeline and TRL for pilot project H₂-C “Heavy Duty Transport”

5.7.4 Pilot Project H₂_D “Distributed production and use in agriculture”

The overall potential of agriculture and forestry in a hydrogen-based economy is although significant, it is often underestimated and complex.

However, with a well thought-out approach, it is possible to demonstrate both utilisation and application possibilities of hydrogen technology as well as synergy effects in demonstration projects in the Fessenheim region. For demonstrating and/or testing valuable pathways and synergetic effects, a concentration on essential core elements and processes would be desirable:

- The use and benefit of biomass for the production of hydrogen
- The use of hydrogen in agriculture
- Synergetic effects and harmony of the use of renewable energy on agricultural land
- Decentralised character in the future image of more independence

The degree of utilisation of biomass for the production of hydrogen, depends on the constitution of the biomass (type, composition, availability, etc.), and on the other hand on the process management for the extraction of hydrogen from biomass. The production of hydrogen from biogas (methane cracking) using renewable energy (e.g. photovoltaics) can be based on established techniques, but should minimise or completely avoid the CO₂ footprint (green hydrogen). Specific agricultural waste products from the region can be used in biogas plants. Grape marc extract from wine-growing can also be used, however it has a big disadvantage of only being seasonally available (only available i.e., during the harvest season). The production of biogas is meanwhile conventional on very different industrial levels. However, the production of hydrogen through methane cracking by means of pyrolysis or plasmalysis has only a TRL of 3-5 and thus it is not yet an industrially established technology. A research laboratory (virtual and real) can be established progressively over the forthcoming years to bring these technologies to a higher technological maturity TRL of 6-9 as an alternative to electrolysis. Direct comparisons on laboratory scale between the electrical input and output (energy content of the hydrogen produced) are promising and can significantly reduce the electrical energy demand for hydrogen production. In addition, the intensive use of agricultural residues and waste materials for the production of biogas (primarily methane) and the generation of hydrogen from methane by means of innovative process technologies (e.g. pyrolysis or plasmalysis) represents a

potential to highlight Fessenheim region as carbon sink. The resulting carbon quantities derived from methane cracking are significant, but could be deposited on land and forest areas and consequently returned to the natural carbon cycle. Some studies on this specific procedure already exist; the verification must be done for demonstration.

Today's modern agriculture is based increasingly on the use of high-tech machinery and vehicle fleets. Fuel consumption is significant, and simultaneously the energy consumption of chopping and cutting machines, hoisting tools and pumps, etc. To meet the requirements, today's tractors and traction engines have high power. A potential for the use of green hydrogen in agriculture thus lies in the combustion machines, i.e. in the vehicle fleet.

The required robustness and limited cooling capacities for those machines promote the application of hydrogen internal combustion engines, like the TCG 7.8 H₂ motor recently introduced by DEUTZ Company¹⁰ (see Fig. 5.23)

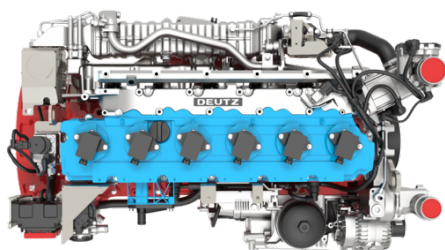


Fig. 5.23: TCG 7.8 H₂ is the first hydrogen engine from DEUTZ ready for the market

Further alternatives of hydrogen use refers to the conversion of diesel engines in tractors and tractor units. The conversion of existing tractors to hydrogen (combustion over an amount of 70% hydrogen, 30% diesel) can help to decarbonise agriculture in general¹¹.

In doing so, the benefits would extend to the entire fleet and upgrade it in parts (performance enhancement). The advantage is that this can be realised with low financial investments in the near future, keeping synergetic effects to be found, for example, in new innovative solar panels and systems (e.g. agrarsolar). Those solar panels work on one side to generate electricity from solar radiation and on the other side could protect high-value crops from indirect consequences of climate change (drought, hailstorms, excessive solar radiation, etc.) (see Fig 5.24).



Fig. 5.24: Potatoes grown under solar panels prototype (Krinner Carport GmbH)¹²

In addition, semi-transparent solar panels are already available on the market but are also under further development (Solarenergie.de 2022)¹².

The dual use of agricultural land involves economic benefit, both, for the farmers themselves and for the local communities and municipalities. In a specific European project called "HyPErFarm, Hydrogen and Photovoltaic Electrification on Farm¹⁴", synergies between using photovoltaic on agricultural lands, options and potentials are investigated and impacts are tested in greater detail.

- Agricultural and forestry land for the use of renewable energy (exploiting synergies)
- Agricultural and forestry products for the production of biogas (from agricultural residues and waste materials, biogenic waste materials from cities)
- Production of hydrogen by means of decentralised plants (methane-cracking by pyrolysis or plasmalysis)

The direct interaction between farmers and municipalities along with its synergies shall demonstrate a win-win situation at different levels and can lead to more acceptance. Basically, it could also be a kind of tourist attraction to launch a demonstration project (e.g. as a hydrogen farm) that demonstrates synergy effects between agriculture and a high technology (photovoltaics and hydrogen technology) and puts its benefits and possibilities in the foreground (showcase). Agriculture can profit from the otherwise lacking acceptance and understanding of the "hydrogen technology", and promotion of renewable energies can benefit the population at large.

It is suggested to install two demonstration plants for this pilot project. The first shall be based on a prototypical

¹⁰ <https://www.krinner-solar.com/apv>

¹¹ <https://solarenergie.de/solarmodule/arten/gebäudeintegrierte-photovoltaik/transparente-solarmodule>

¹² <https://www.ise.fraunhofer.de/de/forschungsprojekte/hyperfarm.html>

<https://www.deutz.com/media/pressemitteilungen/der-wasserstoffmotor-von-deutz-ist-reif-fuer-den-markt>

<https://oekl.at/wp-content/uploads/gems/KLRW2012Kraftstoffverbrauch.pdf>

<https://www.umweltbundesamt.de/daten/flaeche-boden-land-oekosysteme/flaeche/struktur-der-flaechennutzung#die-wichtigsten-flaechennutzungen>

steam reforming process with a relatively high TRL 6-8 (see Fig. 5.25). This installation would follow a past pilot project in the Kaiserstuhl area with a winery. The second installation shall be established using the dark fermentation process.

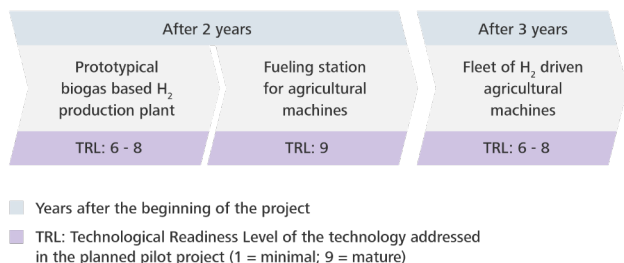


Fig. 5.25: timeline and TRL for the pilots

5.7.5 Green hydrogen hub interfacing with the other activities

In a special workshop, the interface of the 4 competence groups and their pilot project elements have been discussed and analysed.

5.7.5.1 Interfacing with the Twin Quarter project

Electrolysis extends the sector coupling in the power to gas (hydrogen) direction. It allows for storing the otherwise lost excess electricity on a large, seasonal scale. They offer broader exploitation of investments in renewable electricity production from volatile sun and wind via larger capacity factors. Besides, electrolyzers may be operated as a controllable load for grid stabilising. However, coupling requires smart solutions and appropriate management of production, storage and consumption in particular if competing uses of the electricity and green hydrogen are possible. Besides using distributed rooftop PV for electrolysis, also the use of the electrolyzers off-heat has to be integrated for optimising the economies of the twin quarter energy supply. Hydrogen may be re-electrified in fuel cells, motors or turbines or directly used to de-fossilise the heat supply of residential areas. Co-generation is an important element in the demand response mechanisms, which shall optimise the efficiencies and reliability in the energy supply of the twin quarter implementation.

5.7.5.2 Interfacing with the EV Battery Recycling

The complex electricity system actually requires different kinds of storage qualities. This evidently motivates the integration of different chemical energy storages realised with batteries and hydrogen. Second life batteries for fast reactions, high power, but low capacity might be combined with hydrogen-based electricity storage, providing

rather large amounts of stored energy for bridging longer phases without renewable input, up to seasonal storage.

Another important link to batteries will be the investigation of their capability to optimise the electricity supply of electrolyzers.

Finally, it is intended to complement the battery material and recycling pilot project with similar topics for fuel cells and electrolyzers. In many aspects those technologies show commonalities which could be exploited easily.

5.8 Summary and Recommendations

In this chapter the main findings are summarized and the recommendations derived from the findings are described.

5.8.1. Summary

The Multi-Modal Hydrogen Hub Fessenheim is exploring the application possibilities for green hydrogen as an energy carrier in the Fessenheim Innovative Region. It takes part in the feasibility study and has the goal to develop a forward-looking CO₂-neutral economic region which is characterized by its sustainability. The current results of the research show that the use of green hydrogen actually promotes societal transformation and economical changes leading towards a renewable energy supply and a sustainable use of resources. Additionally, new future-oriented jobs will arise.

The hydrogen hub is using a holistic approach which includes all parts of the value chain, beginning with the production of hydrogen, followed by storage, transportation and at last the actual use of the green hydrogen. The Multi-Modal Hydrogen Hub is based on four pilot projects, namely:

- Pilot Project H₂_A "Large scale industry supply with green hydrogen"
- Pilot Project H₂_B "Virtual Pipeline"
- Pilot Project H₂_C "Heavy Duty Transport"
- Pilot Project H₂_D "Distributed production and use in agriculture"

The pilot projects are complementary to each other, yet they use different approaches and have different topics to research on.

The success of the broad implementation of green hydrogen technologies is based on two cornerstones: On the one hand, the viability of a business case for the first private up-takers is of utter importance. On the other

hand, visibility, public support and public acceptance in the Fessenheim area are crucial. If all these requirements are met, the implementation of a desired sustainable CO₂-neutral economic region will be made possible.

5.8.2 Recommendations

Heavy-duty transport, which is subject to Pilot Project H₂_C, could also benefit from this reduced price for green hydrogen. The use of capable fueling stations, which might be modular with research/testing capabilities for fueling protocols etc. is hereby recommended. Also, the identification of users, for example freight forwarding, shipping companies in the Ottmarsheim region and potential suppliers are to be taken into consideration.

Sustainable hydrogen production is achieved either through renewable electricity or biomass. The use of electrolysis is hereby addressed in the research. The recommendation is to place an electrolysis farm near the hydropower plant in Fessenheim and to use floating PV in order to be able to create green energy in the Fessenheim area. To power an electrolyser of around 40 MW initially, it is proposed to use the electricity which is produced by the hydropower plant of Fessenheim to the greatest extent possible.

Furthermore, already available rooftop PV installations, which are located in Colmar, Mulhouse and Freiburg could be incorporated into a central PV electricity harvesting in Fessenheim. Additionally, PV could be placed along highways or on the Sonderlandeplatz Bremgarten (EDTG) which is located just 2 km from Fessenheim.

The pilot project H₂_A also highlights the benefits from combining of hydroelectric power in operation in the area with floating PV: The hydroelectric power plants can be used at night and during days that lack sunlight. PV can serve as an additional renewable electricity source with limited capacity (typically 1000 h/a) at daytime. This is the only working approach to ensure both additionality and the high-capacity factors which are needed to accommodate the economic aspects.

The transport of hydrogen also plays an important role in the research, as it will be necessary in importing and exporting processes. But the construction of pipelines come at big expenses, and they have the disadvantage of not being very flexible. This is where the concept of a virtual pipeline comes into place. The Pilot Project H₂_B "Virtual Pipeline" suggests container-based batch transport via pipeline, roads and through the river Rhine. Using the container solution, losses due to transfer between stationary and transport containers can be prevented and seamless upgrading from high pressure gaseous hydrogen to more dense liquid hydrogen (LH₂) is made possible. Also, this keeps the costs moderate.

Besides that, using this approach, the Fessenheim region can be coordinated with different industrial demand sites

located along the river Rhine and it can be directly attached to Rotterdam, which is the central European landing site for LH₂. This way, the deficiency in supply for LH₂ can be compensated. It is also suggested to enlarge the existing hydrogen pipeline by using a high-pressure pipeline which is operated at a pressure of about 100 MPa. The application of high pressure makes small cross sections possible and might be useful for intermediate storage simultaneously. This could be a pilot for a short distance connection between an electrolyser and the industrial area.

The results of the study show that the industry demand for green hydrogen is higher than in other sectors. Conventionally produced hydrogen can be replaced by green hydrogen. The outcome of Pilot Project H₂_A "Large scale industry supply with green hydrogen" suggests introducing the use of green hydrogen at a large scale with the industry. This can reduce the production costs of green hydrogen considerably, which in turn, opens the possibility for the introduction of the use of green hydrogen in other fields.

Also, the implementation of AGRO-PV for local green hydrogen production is being discussed within the Pilot Project H₂_D "Distributed production and use in agriculture". The use of AGRO-PV on their farmland includes direct advantages for the farmers: Besides the extra income generated for the farmers, AGRO-PV provides protection for the plants against direct sun exposure and also during storms and hail.

The use and benefit of biomass for the production of hydrogen (e.g., methane cracking) is also subject to the Pilot Project H₂_D. In the context of renewable hydrogen production, valorising biomass is a promising approach, in particular when non-valorised agricultural bio waste can be used. Various approaches on the use of biomass are available, namely thermochemical processes, biological conversion processes and electrochemical conversions. Also, the use of hydrogen in agriculture (e.g., combustion engine and fuel cells, H₂ and CH₄) is promoted.

5.9 Interested Industry partners

AIR LIQUIDE
AIR PRODUCTS
LINDE France
MESSER
BADENOVA
BOSTIK
VYNOVA PPC
CONSTELLIUM
BOREALIS
GRIESHABER
SCHENKER
JCL Logistics
RHENUS
ADEKA POLYMER
ALSACHIMIE
BASF
BUTACHIMIE
DSM
DU PONT
EUROGLAS
SCA Tissue
STOCKMEIER
WELEDA
WESTRAN
ABOWind
HYNAMICS / EDF
CRYOSTAR
Siemens
DAIMLER TRUCKS
HYUNDAI

A RAYMOND
BOYSEN
BOYSEN
CLARIANT
DANGEL
DIEHL METERING
EFFBE
EIFFAGE E: - CLEM.
FENWICK-LINDE
NEL
THYSSEN-KRUPP
CUMMINS
ITM POWER
MC PHY
JOHN COCKERILL
LIEBHERR
MTU
MAHLE Behr
MHI Mitsubishi
OELTECHNIK
PLASTIC OMNIUM
PSA
SIELEST

5.10 Contacts

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6. Smart Grids

The transfer towards renewable energies requests new conditions for the electricity network to cope with volatile energy production. In this context, not only the trimming of the existing electricity network is important, but also the intelligent distribution of the produced energy. It is important, especially in the medium and low voltage electricity net to the users for reducing losses linked to energy conversion and to achieve a relatively stable electricity flow. The competence group smart grids was engaged in the development of ideas for pilots testing new intelligent solutions for electricity networks.

6.1 Background

Smart grids are intelligent electrical networks that are being developed throughout the world to constitute the future of electrical networks. They are equipped with highly innovative technologies and they optimize the production and consumption of electricity. The objective is to guarantee a secure, sustainable, and competitive supply to consumers. Smart grids integrate new information and communication technologies such as connected objects. Smart Grids are therefore capable of transmitting real-time information on electricity use and consumption to network operators (producers, distributors and consumers) (Butt et al., 2020). The objective of smart grids is simple: they use the collected information to adjust the flow of electricity and guarantee better energy efficiency in the network. The operating principle is based on all the technologies that collect, analyze and transmit information in real time on the electrical circuit. These technologies allow electrical networks to communicate with each other to ensure a balance between supply and demand, to avoid overloading the network and to ensure a more secure supply.

Smart grids identify several characteristics in terms of reliability, and thus offer a continuous supply of energy when needed, along with the ability of collecting and measuring gathered data in order to maintain the full time service.

Another aspect of smart grids is cyber security and privacy protection, which define an important challenge for smart grids deployment with the consideration of multiple systems involved, making it crucial for a robust and standardized security mechanism to be involved.

One of the most interesting characteristics known for smart grids is the ability of self-healing and fast response whenever a problem occurs. This is due to real time communication and other intelligent components that play an effective role in collecting and sensing abnormal behavior in case of such malfunctions by isolating infected areas, rerouting energy flows etc. This guarantees a full time non-stop energy supply.

Overall, there are three advantages of smart grids:

- **Firstly**, to guarantee the balance between supply and demand:

Electricity is difficult to store and when we need electricity, the energy producers must immediately inject the quantity of energy equal to our need on the network, otherwise the network overheats. So, preserving the balance is essential for the proper functioning of the grid.

- **Secondly**, to meet the ever-increasing need for electricity:

The need for electricity is only increasing with the use of new appliances such as heating, air conditioning, cell phones and computers, electric cars, etc. By providing real time information on the energy flow, smart grids allow network actors to check, control, analyze and optimize energy consumption.

- **And lastly** to participate in the energy transition:

The transformation towards renewable energies, such as wind and photovoltaic, are subject to the vagaries of the weather and their production remains intermittent. At the time of peak consumption, these energies are not always sufficient to meet the immediate needs of consumers. Also, we consider green hydrogen technologies and green batteries which are completely dependent on smart grids for a real time analysis of consumption. The grids allow an excellent knowledge of the state of the network and of the consumption demand in real time. It can be adjusted at any time by integrating other energies such as renewables into the smart grid without altering its efficiency. They allow real-time optimisation of energy use, reduced wastage of energy, electricity and money as well as controlling our electricity consumption. The tool is fully adapted for renewable energy technologies and implicitly it helps to reduce carbon emissions.

6.2 Scope of the smart grids competence group

Smart grids are used for different challenges in the region: energy mix, prosumer, measures, and quality. Scope of the smart grid group is to map the existing transmission system in the transnational region linked to the information on the potentials for renewable energy and the development of scenarios including renewable energy and energy storage in the region or the potential of demand-side management. This first needs the identification of possible weak points on energy usage by updating the electricity network connection concept between France and Germany and to display the expansion of the transmission grids. This then

allows the comparison of available technical alternatives for grid expansion for more renewables in the grid, to increase and optimize the transmission capacity of existing overhead line routes and to analyze the requirements for renewable energy generation plants about system security.

6.3 Potential applications of the smart grids in the region Fessenheim

The challenges behind the cross-border concept for the innovation of the territory of Fessenheim is to integrate the fluctuating electricity generation from renewables in the transnational region and one of the goals is to design and operate the electricity transmission grids, to adjust to other electricity generation plants and demands on the flexibilization of the overall system.

For the smart flexibilisation of the electricity network, the group identified scientific and technical challenges such as: diversity of energy uses, the optimization of systemic energy use in adaptation to the evolution of flexibility needs, the security and usage of the electrical network, the e-mobility and the usage of storage. The group also identifies the economic and societal aspects like the economic model, the social acceptability and the legal and security dimension in a SWOT analysis for the suggested pilots. Among these actions, the Smart Grids group organized a working seminar to define interesting topics with industrial and local authorities.

Based on the input from science, industries and communities, the following objectives were identified:

- To analyse the existing cross-border electricity network and the connector situation between the French-German border in the Upper Rhine
- To develop a cross-border meta-demonstrator in the EcoRhena Innovation parc
- To implement a systemic pilot for different types of city quarters: urban, family-houses or remote village

In the following section we briefly discuss the first objective of analysing the existing cross-border electricity network and the connector situation between the French-German border in the Upper Rhine.

Both Germany and France have dominant electricity production companies in the market, starting with the four companies in the German side: RWE, E.ON, EnBW and Vattenfall also known as "The Big Four" with roughly 82% of electricity production depending mostly on 66% of renewables, and the rest is produced from nuclear, coal and other sources. Other companies share the remaining percentage among them such as *Yello Strom*, *Ostrom*, *Ep-rimo*, *Lekker Energie* etc.

On the French side, the reigning company EDF produces 91% of the electricity alone, leaving the remaining percentage for other companies, naming few: Engie, Total Energies etc. Most of the electricity production comes from around 60% of nuclear and the rest from renewables and other sources. Although power from nuclear energy is still very dominant, there is a reasonably growing percentage of renewables which indicates an already present "Green thinking" in the region for more sustainable energy in promising a responsible and better future.

All the electricity produced in both countries needs to be distributed both on the national and international level and in doing so, other specialized operators are involved. In France, the EDF's subsidiaries RTE for high voltage and ENEDIS for the end consumer, are responsible for the majority of transmissions. As for Germany, we mention four Transmission System Operators: *TransnetBW*, *50 HERTZ*, *Elia Group*, *TENNET* and *AMPRION*.

The mentioned TSOs among with RTE and 34 other operators from 35 countries are members of the ENTSO-E (European Network of Transmission System Operators for Electricity) former UCTE (Union for Coordination of Transmission of Electricity), which made a grid design agreement in order to transmit electrical energy across borders under a state of a unified protocol, via high voltage lines up to 440 kV and the famous grid frequency of 50 Hz for a secure and stable electricity import/export.

According to the ENTSO-E Grid Map, three substations are shared between the French-German border in and around the region of Fessenheim, Eichstetten substation in the German side and two substations on the French side: Vogelgrun substation and Muhlbach substation.

The Eichstetten substation links the other two French substations directly via two cross-border lines with a 220 kV transmission line with Vogelgrun substation, and a 380 to 400 kV transmission line with the Muhlbach substation as shown in figure 6.1.

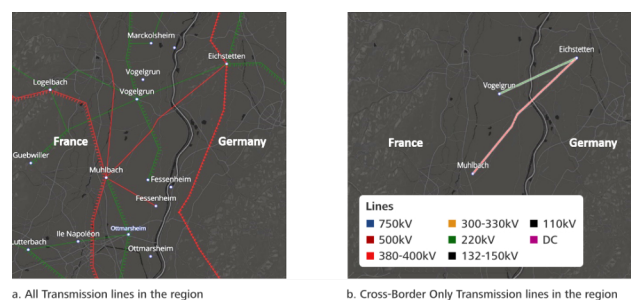


Fig 6.1: Cross-Border Transmission Lines in and around the region of Fessenheim (ENTSO-E Transmission System Map).

The change of meter to a smart meter, which transmits gas, electricity and water consumption, follows a European request of 2009 that provides for the deployment of communicating meters in 100% of European homes in 2022. And this implies the replacement of traditional electricity meters by Linky meters in all households connected to its network by 2021.

According to Enedis, the subsidiary of EDF in charge of the management and development of 95% of the electricity distribution network in France, the Linky meter promotes the development of renewable energies, electric vehicles, self-consumption and allows it to act on energy management. It seems to be essential for the energy transition, with an estimated 20 gigawatts of photovoltaic power, 24 gigawatts of wind power, 1.2 million electric vehicles in homes and 100,000 self-consumption customers.

Despite strong local resistance to Linky, France is among the countries well placed to achieve the European objective. The Linky meter has provoked a real revolt from users, for various reasons: the intrusion into private life, the use of data, and fears about wave emissions from these devices. However, some 11 million Linky meters have already been installed. The French territory, i.e. about 35 million households should be covered by 2021.

Faced with the similar situation, Germany has opted for limited deployment. The law on the "digitalisation of the energy transition", passed in 2016, only concerns the largest customers. So, Germany decided to make the smart meter mandatory only for households consuming more than 6000 kWh per year with an annual consumption estimated at 3500 kWh in 2021. In France, the consumption is estimated around 4200 kWh in 2021, which is 700 kWh more than Germany.

According to the articles of law, the occupants of the dwelling (tenant or owner) do not have the legal right to refuse the Linky meter, as they are not the owners of the electricity meter. In that case, the Linky meter is mandatory. Its obligation is moreover transcribed in several texts, in Law No. 2015-992 of 17 August 2015 for the energy transition and green growth (Article 29), in European Directive 2009/72/EC of 13 July 2009 concerning common rules for the internal market in electricity, and in Article L322-8 of the Energy Code.

When we look at the interactive map for Linky of Enedis for the year 2021 (Fig 6.2), we can see, that 53,109 Linky meters are already installed in Mulhouse. But when we look at the territory of Fessenheim, we see that the town is managed by a local distribution company which provides electricity and gas around Colmar.

In most of France, the distribution of electricity is done by the national network manager Enedis (present in 95% of the territory), but not in Colmar (in the Haut-Rhin) where it is the an ELD (Entreprise Locale de Distribution), which is responsible for the electricity distribution network. This is because Colmar has a special status in the French energy market and as a result, the historical supplier EDF is not present in Colmar. Most alternative electricity and gas suppliers do not offer their services in this town either. If they want to subscribe to an electricity offer, Colmar residents must contact Vialis, the local distribution company (ELD). It is the only electricity supplier in the region to offer the current regulated rates.

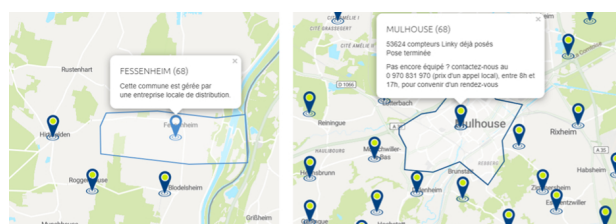


Fig 6.2: Map of Linky installations on the perimeter of Fessenheim and Mulhouse in 2021

- In the following section we briefly discuss the second objective of developing a cross-border meta-demonstrator in the EcoRhéna Innovation parc.

The business park EcoRhéna located in the region of Fessenheim represents a strategic spot for a variety of investments with an already settled all purpose platform. It attracted many companies like Constellium, EDF, Fiberweb, FMC, Knauf, Wrigley, but also many SMEs (Small and Medium Enterprises) like Adecco, Egja, Panthera sécurité, Green Concept etc.

Previously, a company called Européenne de Biomasse initiated feasibility studies at EcoRhéna in order to expand its subsidiary the HPCI (a 100% renewable energy biofuel using wood industry residues) for energy transition in the area.

With such a huge industrial park, energy supply is needed continuously and therefore smart grid installation is mandatory for an efficient, reliable and well managed energy fueling.

- The third objective of implementing a systemic pilot for different types of city quarters: urban, family-houses or remote village is discussed in section 6.5 of pilot project development.

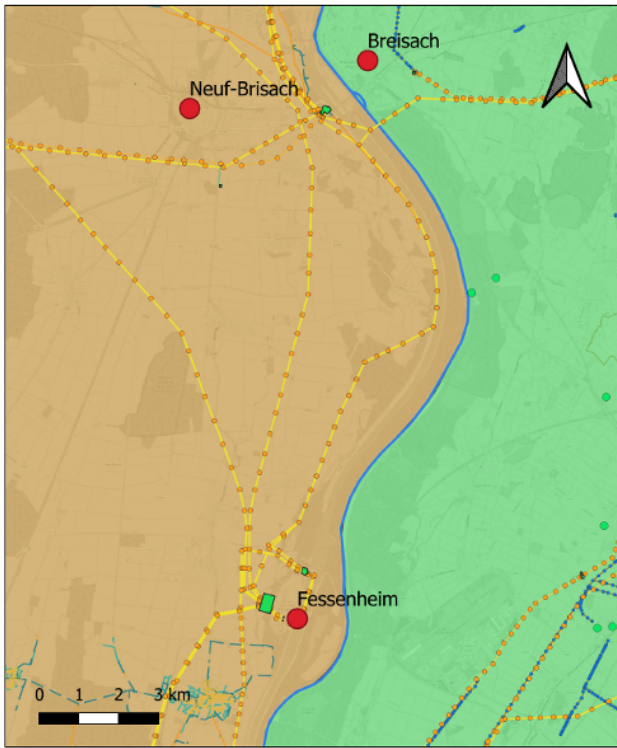


Fig. 6.3: Section of the electricity network in the Upper Rhine region and important transnational connectors

6.4 Assets and challenges for the implementation of smart grid in the region

The following paragraphs will identify the assets and the needs:

6.4.1 Potentials and demands

For the envisioned installations, companies, communities and funding agencies especially under the EU green deal program need to work together for a pilot role model.

Systemic overall concept for the regional transformation towards CO₂ neutrality and circular economy:

- Increasing the use of renewable energies such as photovoltaic panels, towards a free carbon-neutral Upper Rhine area
- Showcase of systemic energy flexibility and energy efficiency usage for city quarters and industrial sites to represent the future energy system in a real-world lab
- Revitalization of existing industrial sites and transformation of existing urban city quarters
- Energy management (ISO 50001)
- Modeling grids structures of various types of city quarters and industrial sites in France and Germany

- Constitution of a usage and production database for scenario learning using AI tools

Status

In the Smart Grids group, we contacted a lot of companies and local authorities that were interested in energy management and energy sector, where mostly their R&D support wanted to participate in a more effective way to consume energy on-time. The smart grids group wants to propose the development of projects and pilots at a regional scale with the knowledge and scientific expertise of the territory. It is thus then important for the smart grids group to identify the key players, to create contacts and to establish a consortium.

Potentials

In the Upper Rhine area, we find all the industrial players from energy production to consumers (energy management, chemicals, automotive, etc.) and all the engineering services necessary for the development of pilot projects.

In addition to having all the technical and scientific skills needed to carry out pilot projects, many local authorities and companies are committed to strategies for modifying industrial sites or neighborhoods in order to reduce their carbon impact, or even to achieve ISO 50 001 certification. All these initiatives are fields of action in which the partners of the feasibility project can intervene in cooperation with companies and local authorities.

Challenges

As previously mentioned there is immense interest among the industry players in smart grid technology. However, the lack of conviction of companies to invest in installations in the Fessenheim region poses the biggest challenge so far. For a successful transformation of the region, there is an ardent need for companies that are willing to participate in the building and operation of some of the envisioned installations.

The smart grids group thus proposes research and innovation that brings industrial players and researchers together to create a bond of trust for a consortium and to create sustainable jobs.

6.5 Pilot development based on potential industry settled in the Upper Rhine

Today, smart grids can support existing industries and companies in the Upper Rhine, so we will explain which sectors or situations we are targeting.

6.5.1 Smart Twin quarters

The Smart East Karlsruhe project, performs projects in a mixed commercial and residential area. Existing buildings in the east of Karlsruhe are being transformed into an energy-optimized smart district. The project aims to evaluate and economically assess a renewable and climate-neutral energy supply as well as is testing new business models compatible under these circumstances. The digitalisation of the energy supply, sector-coupled networking, and an integrated optimisation and operating model are being implemented in this project and transferred into practice (Seven2one Informationssysteme GmbH, 2022).

Within this three-year Smart East lighthouse project, a collaboration of research institutes, IT and energy companies aims to realize a smart neighborhood in Karlsruhe East. The existing buildings will be digitized with smart meters and networked in a neighborhood energy management system. The electricity, heating, cooling and transport sectors will be linked and new business models for energy cooperation will be tested. Through this approach, a climate-friendly energy supply for an existing urban quarter with commercial and residential areas is being created as a real laboratory (Seven2one Informationssysteme GmbH, 2022).

Another important core target is a transformation to a smart neighborhood which is economically worthwhile. The project partners are therefore developing new business models that pay off for the various actors. On the basis of practical experience, the project participants are developing recommendations for action that can also be transferred to other neighborhoods.

The goal of the project is to demonstrate how a smart neighborhood can be built and how new business models and marketing opportunities can be realized. In order to ensure the link between the practice and the subsequent transfer of the results, potential users (for example municipalities, the housing industry, real estate developers, commercial park operators or public property operators) are expected to accompany the project (Ministerium für Umwelt, Klima und Energiewirtschaft Baden-Württemberg, 2022).

The overall mission is that the Smart East commercial quarter in the Oststadt district of Karlsruhe will become a smart, energy-optimized, climate-friendly quarter (Seven2one Informationssysteme GmbH, 2022).

The Smart East Karlsruhe project is a collaboration of FZI (Forschungszentrum Informatik), Seven2one Informationssysteme GmbH, Karlsruher Institute of Technology (KIT), Institute for Automation and Applied Computer Science and Stadtwerke Karlsruhe GmbH (Seven2one Informationssysteme GmbH, 2022).

Connecting Fessenheim with this quarter in Karlsruhe as well as other innovative quarters like the Fonderie in Mulhouse gives the opportunity to compare different Smart Grids and to gain information about the challenges and opportunities of tomorrow's electricity network.

6.5.2 Charging stations (tourism and public transport)

At the end of 2021, the Mulhouse m2A municipality launched a call for private initiative projects, with the aim of increasing the number of recharging stations in strategic sectors of the Mulhouse agglomeration. The aim is to make the electric vehicle users be able to recharge their vehicles in the public domain. The relevant questions raised are the choice of the type of charge (slow, fast), their placement, their connection to the electrical network and the economic model for the use of these charging stations. Solutions do exist, for example a deployment of this type has taken place in Lyon by an EDF subsidiary (IZIVIA), but a lot of work on optimizing the scheduling and economic modeling remains to be done. Such experiments also exist in Germany. The German state of Baden-Württemberg is continuing to support pilot projects for the intelligent connection of underground parking lots to the grid. More than seven million euros are available for the installation of charging stations for the electric vehicles in covered parking lots, parking garages and underground garages. This is done as part of the INPUT 2.0 promotion competition.

In essence, offering the electric mobility solutions between Germany and France by providing charging stations on both sides of the border, would be a beneficial step towards energy transition.

6.5.3. Energy grid consumption comparison mapping between France and Germany to integrate into European grid development

The goal of the smart grid competence group is to map the existing regional transnational transmission system and collect information on the potential of renewable energy and its link to scenario development for the regional energy grids. Additionally, the goal is to study the potential of demand-side management. Hence, it is imperative to identify possible weak points in terms of energy availability. Ideas for updating the electricity network connection concept between France and Germany and for displaying the expansion possibilities of the transmission grids is another focus of this group. Implementing such concepts allows the comparison of the technical alternatives available for grid and connector enhancements and supports the expansion towards more renewables. The development of discrete concepts also develops better ideas for optimising the transmission capacity of existing overhead line routes

and analysis of the requirements for system security in renewable energy generation plants. One of the main challenges in the cross-border concept is to integrate the fluctuating electricity generation from renewables in the transnational electricity network. Thus, the goal is to design and operate an electricity transmission grid which is both flexible and adapted to different electricity generation plants. For the cross-border innovation concept, the goal is to design and operate the electricity transmission grid in the Fessenheim territory and adjust to the diverse electricity generation plants as well as the demands for more flexibility in the overall system.

The competence group's analysis highlights the technical challenges like diverse energy use, security and usage of the electrical network, and the grid integration of e-mobility and further storage capacity. There are also socio-economic challenges such as suitable economic models, social acceptability, and legal and security constraints.

6.6 Local Smart grids application

In order to implement a Smart Grid System, following a set of steps needs to be recognized:

- **Substation Automation**

Electricity substations and central stations need systems that allow automation offering supervision and control, and efficient monitoring, with real-time diagnostics without interfering with its productivity.

- **Advanced Metering Infrastructure**

Smart Meters offer a two-way communication allowing a real-time monitoring and data collection periodically for a better consumption analysis conducting to a better network awareness.

- **Demand Response**

The key goal of the demand response application is for the utility company management of the consumer-side electrical loads. This is done by enabling the interconnection of all smart grid components (electrical vehicles, micro grids,...) allowing an efficient way to interfere in order to optimize load shifting.

- **Distribution Automation**

The distribution automation system ensures power reliability and availability in the grid by analyzing data collected by utility companies in an automated/monitored way to optimize power grid efficiency.

- **Energy Management System**

It is used to control and monitor the electricity transmission system to avoid any malfunction in the power grid supply.

6.7 Pilots projects

The implementation of the smart grids projects comprises 3 proposals for pilot projects composed of:

- Pilot project SM_A "Twin quarters Mulhouse - Karlsruhe"
- Pilot project SM_B "European grid development"
- Pilot project SM_C "Electric vehicles charging stations grid"

These projects need to be accompanied by industries and companies of the Upper Rhine area.

6.7.1 Pilot project SM_A "Twin quarters Mulhouse - Karlsruhe"

In the city of Mulhouse there are two possibilities of integration of smart grids. The first one in the Fonderie quarter which includes industrialists and the second one in the DMC quarter with a mix of uses in development.

In Karlsruhe, such a project is ongoing in the East quarter for the energy transition in the city as mentioned in the preceding section. This project is in collaboration with KIT and Seven2one.

For the Fonderie quarter, the city of Mulhouse is planning to set up businesses and the idea is to create a sustainable quarter between already existing smart grid quarters in Karlsruhe and Mulhouse and to create an exchange of expertise between both. The goals of these twin projects are:

- Reducing energy consumption and increase efficiency
- Integrating renewable energy and storage
- Coupling electricity, heat and cold
- Integrating and developing e-mobility
- Analyzing the uses, creation of learning databases
- Developing respective business models
- Creating an exportable model (ex: EcoRhena)
- Labellisation ISO 50 001, Energy Management
- Becoming "climate cities"

The next steps are :

- Create a consortium for Mulhouse (already existing at Karlsruhe)
- Define common objectives (sharing of competences and ideas)
- Develop acceptability and an economical model

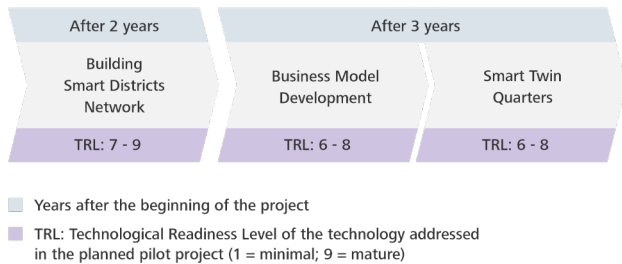


Fig. 6.4: Timeline and TRL for pilot project SM_A "Twin quarters Mulhouse - Karlsruhe"

6.7.2 Pilot project SM_B "European grid development"

The objective of this pilot is to solve the problem of stability of electric power distribution including the connection of the German and French networks with electric interconnections development: high level (some GW) middle level (less than 1 GW). The objective is also to tackle the issue of energy mix integration on the grid at an European level.

The specific goals are :

- To ensure a robust stability of the grid, keep the frequency close to 50Hz
- To optimize the energy mix towards decarbonization
- To integrate local grids with transnational grid
- To enhance the commercial transaction balance

The next steps are :

- Collaboration between NetzeBW/TransNetBW and RTE (already existing thanks to the Fraunhofer ISE).
- Define the scientific open questions
- Join grids simulation (ex: RTDS / OPAL-RT)

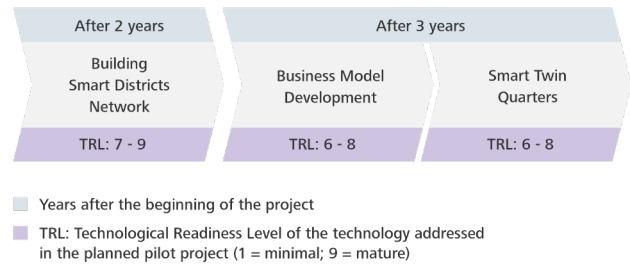


Fig. 6.5: Timeline and TRL for pilot project SM_B "European grid development"

6.7.3 Pilot project SM_C "Electric vehicles charging stations grid"

The objective of this pilot is the management of the location of electrical charging stations, charging strategy, storage strategy and development of charging points numbers in cities.

One concrete example is Mulhouse Agglomération (m2A) with 150 new points of electric charging stations. Also, the Black Forest region or the city of Freiburg could be a prototype region to see how e-mobility can be integrated as battery storage in the electricity grid.

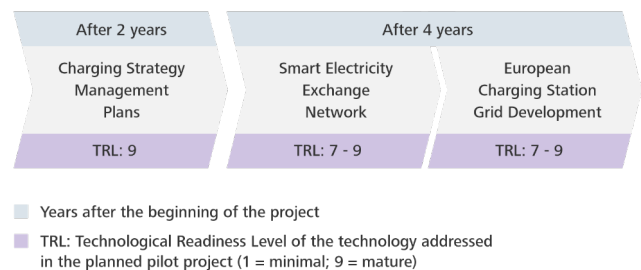


Fig. 6.6: Timeline and TRL for pilot project SM_C "Electric vehicles charging stations grid"

The following table provides an overview on the strength, opportunities, weaknesses and threats for the Smart Grid pilots.

<p>Strengths</p> <ul style="list-style-type: none"> • Experience and knowledge in Energy Management • (ex: ISO 50 001) • Several contacts with local companies 	<p>Weaknesses</p> <ul style="list-style-type: none"> • Data collection (ex: smart meter)
<p>Opportunities</p> <ul style="list-style-type: none"> • Revitalization of a neighborhood with new installations towards carbon neutrality (Fessenheim, Mulhouse, Karlsruhe) • Transversality towards the other competence groups (green batteries and hydrogen) 	<p>Threats</p> <ul style="list-style-type: none"> • Local policy • Societal acceptability within the citizens

Tab. 6.1: SWOT analysis on Smart Grid implementation

The installations, envisioned by the Smart Grids group, have the potential to generate jobs in the Fessenheim region, especially pertaining to battery technology expertise. Also, as the energy consumption control is critical, the installation of smart meters or similar devices will be promoted. Moreover, job potentials can also vary depending on the combination of other technologies that can complement smart grids, such as hydrogen, which can even increase job developments. Due to the universities located in Switzerland, France and Germany that teach relevant competencies, people with the required expertise are already available in the Fessenheim region.

6.8 Summary and Recommendations

The following summarizes the findings and provides an overview on the recommendations.

6.8.1 Summary

In this feasibility study, the Competence group Smart Grids, suggests possible installations dealing with battery storage options linked to charging stations and also for a controlled and saved electricity consumption with a consumption on demand. The idea is to integrate smart grids in Fessenheim, but also in the perimeter of Mulhouse and Karlsruhe to create areas and districts equipped with smart grids for better energy consumption.

There are a lot of opportunities to install smart meters by innovative quarters in Mulhouse (Fonderie) and Karlsruhe (Smart East), and also with the city of Mulhouse CeA that just launched a call for battery charging stations for vehicles.

However, the biggest challenge for the implementation of pilot ideas is to convince companies to accept and invest in the installation of a smart meter.

In addition, the impact on the electricity grids with increasing renewables shall be investigated by modeling approaches.

6.8.2 Recommendations

We recommend following the holistic approach described in this feasibility study by realizing as many of the suggested facilities from the different competence groups (batteries, hydrogen, and smart grid).

The Smart Grids competence group recommends the installation of a smart grid system in two neighbourhoods (Pilot 1) in France and Germany, as testbeds for smart grid management scopes like controlled and efficient electricity consumption on demand. The idea is to integrate smart grid systems in neighbourhoods of Mulhouse and Karlsruhe. The location is selected due to communal level openness available for building such a pilot: in Karlsruhe, the implementation of the smart grid neighbourhood has already started, while the commune of Mulhouse is willing to invest in such an idea. The transfer of the gained know-how from the smart grid systems tested in the two city neighbourhoods to the planned implementation of the French-German innovation Parc EcoRhena, as an example for a cross-border meta-demonstrator is recommended. With this pilot, the following goals will be achieved: a demonstration of how smart grids support the reduction of energy consumption, the integration and intelligent storage of renewable energy, the coupling of electricity sources, heat and cold management, and the creation of exportable models.

The group recommends testing the integration of e-mobility batteries into the smart grid system, along with the implementation of the smart grid neighbourhoods (pilot 2). It will help to understand in an effort to gain knowledge on how this integration can enhance electricity grid management and how technical, economic, and societal barriers can be solved. The goals of this pilot are to improve the understanding of how to optimize the charging station network of a district and the coupling between the charging load network and the distribution network. This will facilitate in reducing power peaks with e-mobility battery storage use, achieving the best profile and usage models, supporting the cross-border standardisation of charging

networks. Hence, e-mobility charging stations for cars and bikes need to be included in the design of the smart grid neighbourhoods. It is suggested to start with industrial neighbourhoods by establishing electrical charging stations as test-beds for smart grid applications. As an outcome, it could show how e-mobility charging stations integrated in a smart grid can help save energy and optimize energy distribution in terms of availability as well as accessibility.

Another recommendation is to map out (Pilot 3) the existing regional electricity grid and analyse its weaknesses for optimal cross border electricity exchange. Furthermore, it is recommended to study the ability of regional electricity grids to stabilize under volatile electricity production. The goals of this pilot are based on European Union Energy Policy, which include stabilising the grid by keeping the frequency at 50Hz, optimising and decarbonizing the energy mix, and integrating the local grids with the transnational grid. The capacities of the existing networks and load profile simulations for the different scenarios of renewable installations provided by the RES-TMO study should be part of this pilot.

Therefore, we emphatically suggest that each working group be involved in all these projects because smart grids can be applied to different types of projects. Moreover, working together on the same ideas will greatly enhance the effectiveness and scope of this feasibility study.

6.9 Interested Industry Partners

ACTEMINIUM ROMANDIE.

ALSACHIMIE

BUTACHIMIE

CCI ALSACE EUROMETROPOLE

CETIM GRAND EST

COMMUNAUTÉ DE COMMUNES SUD ALSACE LARGUE

CRYOSTAR SAS

EDF - Direction Action Régionale Grand-Est

EIFFAGE ENERGIE SYSTÈMES - Clemessy

ENGIE - Délégation Régionale GE Et Territoriale Alsace

GAUSSIN SA

GROUPE HOSPITALIER DE LA RÉGION DE MULHOUSE ET SUD-ALSACE

GRTGAZ - Délégation Territoriale Nord Est (Nancy)

H₂SYS

HAFFNER ENERGY

HOLCIM HAUT-RHIN

KMO

LAFARGE HOLCIM - Research Center

LIEBHERR-FRANCE SAS

LONZA - CAPSUGEL

MOBASOLAR

MUSÉE ELECTROPOLIS

REISA - Réseau des Entrepreneurs Innovants du Sud-Alsace

RTE- Réseau de Transport d'Électricité (Délégation Est)

SAINT-LOUIS AGGLOMÉRATION

SCHNEIDER ELECTRIC - SITE DE METZ

SHARELOC

SHERPA MOBILE ROBOTICS

SOCOMEK

SOLEA - TRANSPORTS EN COMMUN DE L'AGGLOMÉRATION MULHOUSIENNE

STÄUBLI RACCORD FRANCE AGENCE EST

STELLANTIS

TRION-CLIMATE

VINCI CONSTRUCTION GRANDS PROJETS

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7. Territorial Framework

The development of the industrial installations and technologies necessary for a sustainable, circular and de-fossilized economy requires their successful integration on the territory from a societal, environmental, economic and regulatory point of view. The fourth competence group assessed the framework conditions for the implementation of the pilot ideas developed in the feasibility study.

7.1 Background

The frame for implementing technical innovation is of high relevance if this implementation is to be a success. The following study analyses this framework of conditions while focusing on the innovation region. This contribution aims to allow the establishment of a baseline "T0" of societal, environmental and regulatory aspects during the feasibility phase - a photograph at time zero of the territorial framework. A close look at these very same issues will be necessary in the implementation phase of technological projects to ensure the prospective monitoring of the evolution of the territorial framework and consolidate the final objective of the project.

7.2 Scope of the Territorial Framework Competence Group

Through its network of Franco-German scientific experts, this competence group aims to evaluate concrete ideas related to "Green Batteries", "Hydrogen" and "Smart Grids" technologies for the green transformation of the territory Innovation Region Fessenheim (Fig. 7.1). The evaluation was carried out by:

- Identifying the values which citizens and local stakeholders believe in for a better understanding of their perceptions and expectations vis-a-vis these technologies, through acceptability studies;
- Offering an assessment of the environmental impacts of the technologies mentioned, notably through studies of territorial metabolism and life cycle analysis, for the establishment of a viable economic basin and a pilot region in terms of low-carbon energy transition;
- Studying the current regulatory context (French, German and European) in the three targeted areas to give a global vision of the legal framework in which industrials must structurally and technologically fit, through the study of a targeted regulatory and legal compilation.

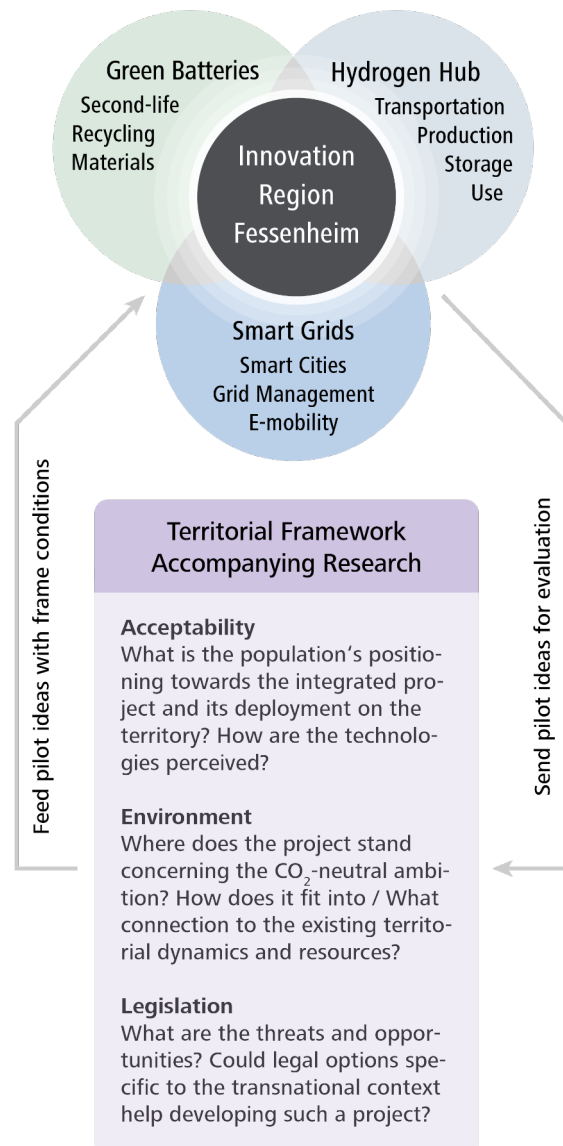


Fig. 7.1: The Interconnection of the Territorial Framework group and the other competence groups.

7.3 Social Acceptability

7.3.1 Social Acceptability of a Territorial Deployment Project of an Energy Innovation

Feasibility studies often focus on the technical and economic feasibility of a project, yet sometimes fail to consider the potential uses or the perceptions and needs of affected populations near the deployment site. Such an approach may hinder the overall understanding of the issues. Therefore, it is necessary to take a broader look at the question of adoption and acceptability. Societal needs, perceptions and possible changes as well as ethical ques-

tions in terms of fairness (e.g., regarding the procedures and distribution of benefits and costs) of the technology by potential users or local residents are to be considered. This work explores the notion of social acceptability as a boost to the implementation of a territorialised deployment project of an energy innovation with the following implicit question: how to obtain the support of the public affected by a project to ensure its sustainability?

Based on an extensive literature review¹, several hypotheses have been put forward regarding the determinants of social acceptability. An exploratory method known as perception-based regional mapping (PBRM) was then used to verify these hypotheses and assess the local residents' perception of a project (Clouet, 2000; Caron et al., 2005). PBRM is a spatial method to support regional development initiatives. It consists of a spatial participative mapping that draws attention to citizens' awareness/sensitivity on a given territory (Saqalli, 2015).

PBRM was performed in the Communauté d'Agglomération de Sarreguemines. This area houses FaHyence, the first hydrogen refuelling station producing its own hydrogen (FaHyence, 2017). The location of this demonstrator has some climatic and geographic common ground with the Fessenheim area (proximity to the German border). Thus, FaHyence could be suitable for benchmarking - in the case of the hydrogen competence group - and a typical comparative study could be performed. It could potentially highlight problems related to the implementation of such demonstration projects and help improve the design of future projects.

The results of our research are compiled in the form of SWOT analyses (Tables 7.1, 7.2 & 7.3) to present factors that are favourable or unfavourable to the territorialised deployment of each type of technology from the perspective of social acceptability.

1 Green Batteries	
<p>Strengths</p> <p>Downstream high acceptability due to a positive environmental image:</p> <ul style="list-style-type: none"> • Longer battery lifetime • Possibility to recycle battery • Reduction of the depletion of scarce resources (reduced abstraction) <p>Local energy storage (second life of battery) for personal usage.</p>	<p>Weaknesses</p> <p>Lack of information on the recycling possibility.</p> <p>If technologies on materials used for batteries evolve, uncertainty about continuity of recycling processes may arise</p>
<p>Opportunities</p> <p>Develop a positive environmental life cycle:</p> <ul style="list-style-type: none"> • Extend lifecycle • Ability to recycle materials 	<p>Threats</p> <p>Upstream weak acceptability due to a rebound effect linked to the exploitation of scarce resources whose availability is by definition limited</p> <p>Energy dependency: threat of blackout due to growing demand for electricity</p> <p>The tolerance for the installation of this type of plant: potential pollution from a battery recycling plant is likely to affect the cost-benefit ratio</p>

Tab. 7.1: SWOT analysis related to Green Batteries.

¹ See literature with * in chapter 7 references.

2 Hydrogen	
<p>Strengths</p> <p>Acceptability is not consumer-dependent</p> <p>Little or no NIMBY effect²</p> <p>Low risk perception</p> <p>Use of a low-polluting asset (no particle emission)</p> <p>Storable energy production: act as buffer = compensates for RE intermittency</p>	<p>Weaknesses</p> <p>Lack of information on origin / mode of hydrogen production (really green?): green hydrogen might be confronted with criticism if not explained well enough and if it is not part of a holistic concept of energy transition.</p>
<p>Opportunities</p> <p>Feasibility depends on political will</p> <p>Potentially promising: positive environmental image</p> <p>Territory attractiveness / ecological trajectory</p>	<p>Threats</p> <p>Lack of information</p> <p>Lack of trust in project sponsor</p> <p>Cost of transportation and grid connection of hydrogen</p>

Tab. 7.2: SWOT analysis related to Hydrogen

3 Smart Grids	
<p>Strengths</p> <p>Acceptability linked to smart management of energy consumption:</p> <ul style="list-style-type: none"> • Bill under control • Energy savings: positive environmental impact as better information helps to involve the consumers behaviour: they lower their consumption accordingly 	<p>Weaknesses</p> <p>Individual risk perception linked to:</p> <ul style="list-style-type: none"> • Radiations / waves • User and usage tracking • Computer hacking • Fear of bugs • Electricity theft • Control of personal data (ex: of their home) <p>Lack of intelligibility in the data use charter</p> <p>Lack of vision on the real contribution of smart management in terms of energy consumption reduction. Is the contribution of smart management profitable in terms of cost/benefit ratio?</p>

² NIMBY (Not In My Back Yard): opposition by residents to the development of infrastructure in their surrounding area.

<p>Opportunities</p> <p>Trust level</p> <ul style="list-style-type: none"> • Depends on level of information • Need for data use charter <p>Appropriateness:</p> <ul style="list-style-type: none"> • Comfort of use / ergonomics (usage “intuitiveness”) • Human / machine interface 	<p>Threats</p> <p>Risk perception linked to cybersecurity</p> <p>Will the development of the grids be sufficient to compensate for the growing consumption of electricity in the coming years?</p>
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Tab.7.3: SWOT analysis related to Smart Grids.

7.3.2 Psychological Determinants of Social Acceptability

The brakes and levers of social acceptability were also studied from a psychological perspective. The psychological determinants of the social acceptability of the envisioned technologies were identified through previous works (Emmerich et al., 2020; Huijts et al., 2012; Huijts et al., 2014; Tumilson & Song, 2019). They provide support for including variables such as trust, benefit-cost perception, affect, and knowledge as psychological factors accounting for social acceptability. Our measurement strategy consists of a questionnaire (Questionnaire, 2021) to be distributed to the population.

The variables were assessed by selecting specific scales for each. Table 7.4 lists variables and corresponding examples mostly related to hydrogen technology. Questions were also adapted for green batteries and smart grid technologies. Each participant was limited to one technology only.

The questionnaire was distributed to the French population. No specific location was targeted. A dissemination platform was used in order to collect enough data. We primarily focused on the general French population. The study sample was large and slightly mirrors real conditions where the whole population is concerned by the energy transition with the political will to lower/remove the contribution of nuclear sources in the energy mix over time.

The results of our research are presented in the following order. We first compare where all three technologies (Green batteries, Hydrogen, Smart Grids) stand regarding each variable of interest. Second, we detail some of the existing relationships between the different variables and the social acceptability of the technologies considered.

Variables	Examples
Trust (Tumilson & Song, 2019)	<ul style="list-style-type: none"> • How much would you trust environmental groups to provide reliable information about green technologies?
Benefit Perception (Tumilson & Song, 2019)	<ul style="list-style-type: none"> • What are the new economic benefits that hydrogen may bring to your community ? (e.g., job creation)?
Social Acceptability (Batel et al., 2013)	<ul style="list-style-type: none"> • In general, I accept hydrogen. • To what degree would you agree to the construction of hydrogen dedicated facilities near your community?

Tab. 7.4: Examples of variables and related scales used for the study.

7.3.2.1 Descriptive Study

- **Objective Knowledge**

Objective knowledge was assessed through sets of true/false questions (one set per technology). Each set consists of five specific and factual questions which are related to each technology and were constructed after consultation with the other competence groups. Results show that people have more objective knowledge about Smart Grids than Green Batteries and even less about Hydrogen (Fig. 7.2). The percentage of respondents that got 4 to 5 correct answers out of 5 reveals that they have a relatively good level of knowledge about Smart Grids (51%) and Green Batteries (46%) and a rather modest level of knowledge about Hydrogen (24%).

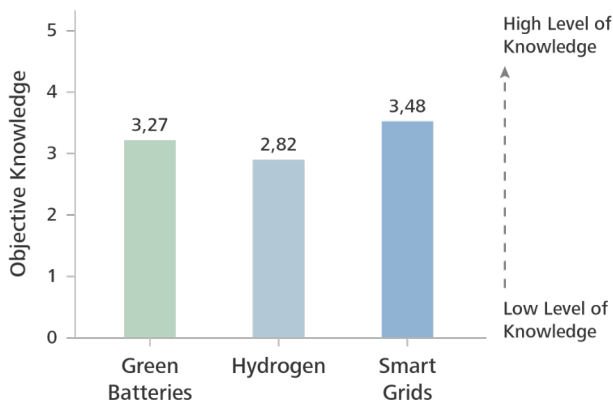


Fig. 7.2: Objective knowledge associated with each technology ("0" indicates a low level of knowledge, "5" indicates a high level of knowledge).

- **Affect**

Participants were asked to indicate up to three words elicited by the technology presented. 'Gas', 'water' and 'energy' were most frequently associated with Hydrogen. 'Recycling', 'ecology' and 'pollution' with Green Batteries and 'electricity', 'economy' and 'technology' with Smart Grids. Elicited words should then be rated as very negative, negative, neutral, positive, or very positive. Of the three technologies, Hydrogen has the best image (positive affect), followed by Green Batteries, and finally Smart Grids (Fig. 7.3).

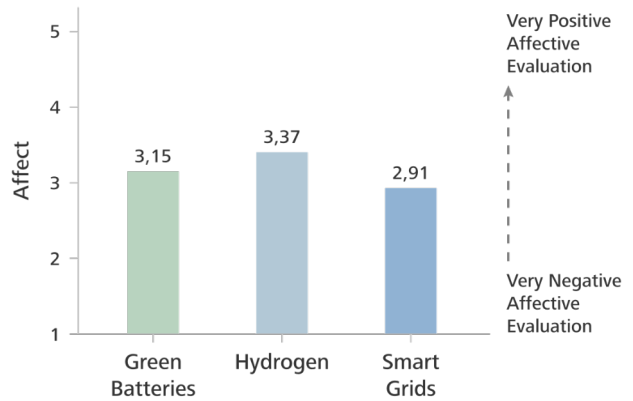


Fig. 7.3: Affect towards each technology ("1" indicates a very negative affective evaluation, "5" indicates a very positive affective evaluation).

- **Benefits and Costs**

Benefits and costs were assessed through a set of height questions (four for benefits, four for costs) covering different topics related and adapted to each of the technologies (territorial, environmental, economic, healthy/safety aspects, etc).

As far as benefits are concerned, Hydrogen is perceived as more beneficial than Green Batteries, and Green Batteries more beneficial than Smart Grids (Fig. 7.4). Irrespective of the technology, the environmental benefit was considered to be the most important.

As far as costs are concerned, Green Batteries are considered to have the highest cost, followed by Smart Grids and then Hydrogen (Fig. 7.4). Irrespective of the technology, the financial cost (infrastructure construction, maintenance, etc.) was considered to be the most important.

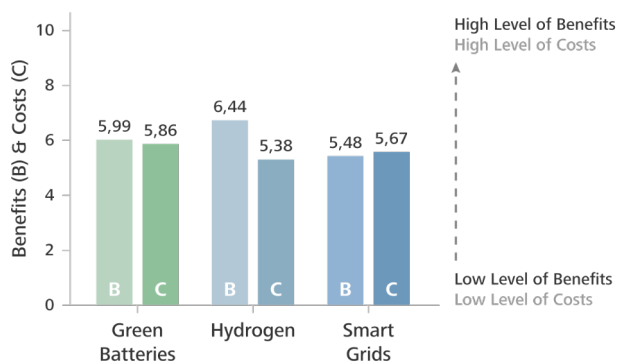


Fig. 7.4: Benefits and costs associated with each technology ("0" indicates a low level of benefits – respectively, a low level of costs, "10" indicates a high level of benefits – respectively, a high level of costs).

Finally, it should be noted that the benefit-cost balance (i.e. the difference between benefits and costs) is positive only for Hydrogen. Hydrogen is perceived to be more beneficial than costly. For Green Batteries and Smart Grids, benefits and costs are in overall balance.

- **Social Acceptability**

Social acceptability was assessed through two questions. One focusing on global acceptability, i.e. being in favour of the development of such technologies in general, the second on local acceptability, i.e., being in favour of the installation of such technologies in the surrounding areas. On average, global acceptability was considered higher than local acceptability, regardless of the technology, and possibly reflecting a NIMBY effect (Not In My Back Yard). Further, responses to both questions were strongly correlated ($r = 0.75$)³ leading to considering them in a single social acceptability score (Fig. 7.5). In doing so, Hydrogen appeared to be the most acceptable technology, followed by Green Batteries and then Smart Grids.

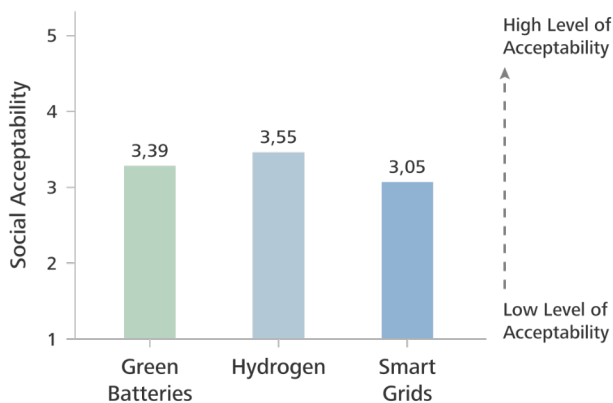


Fig. 7.5: Social acceptability for each technology ("1" indicates a low level of acceptability, "5" indicates a high level of acceptability).

These first descriptive results seem to indicate that Hydrogen is the technology best perceived by the population in terms of image (positive affect), perception of benefits (positive benefit-cost ratio) and acceptability. The level of objective knowledge does not seem to play a role in the way the technologies are perceived.

- **Trust**

Regardless of the technologies, we assessed the level of trust placed in different stakeholders on two topics: reliability of the information provided about new technologies, and "ensuring that production facilities and plants for new green technologies comply with safety rules".

A preliminary analysis showed that the topic does not seem to matter much. The stakeholder itself prevails. We therefore grouped the scores of the two questions into a single score per stakeholder. It then appeared that trust in local representatives, government, and industrials was generally at the same level. These three stakeholders were then grouped into the single entity called "institutions" (political and economic). Participants generally placed less trust in these institutions than in environmental organizations (Fig. 7.6).

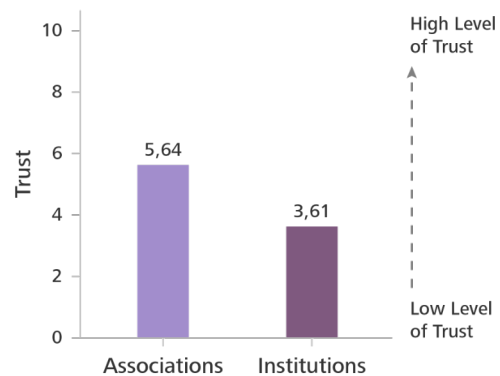


Fig. 7.6: Level of trust according to the type of stakeholders ("0" indicates a low level of trust, "5" indicates a high level of trust).

7.3.2.2 Levers for Social Acceptability

In this section, we explore correlation between the variables of interest. In other words, we are interested in the degree to which the abovementioned variables are related to social acceptability. The objective is to identify levers on which it is possible to act in order to improve the acceptability of the technologies under study. The results are as follows:

- The level of objective knowledge appears to be weakly related to both the degree of social acceptability of any of the technologies ($r = 0.13$) and the other variables ($0.05 < r < 0.13$). It might indicate that knowledge has a negligible impact on acceptability, but also on the image the technologies convey, or the perception of their benefits or costs.
- The affect towards a technology appears to be strongly linked to both its acceptability ($r = 0.53$) and the associated benefits ($r = 0.49$). It is less related to the associated costs ($r = -0.11$). In other words, the better the affective evaluation of a technology, the more acceptable and beneficial it appears to the public.
- The benefits associated with the technologies are positively and strongly related to their degree of ac-

³ r indicates the strength of the relationship between two variables. It varies from -1 to +1. The further it is from 0, the stronger the relationship.

ceptability ($r = 0.51$). The more beneficial the technologies are perceived to be, the more acceptable they are. The perceived costs seem to play a much less important role in their acceptability ($r = -0.13$).

- The level of trust in associations or institutions seems to play a similar, rather modest role (respectively, $r = 0.16$ and $r = 0.18$) in the acceptability. Trusting or distrusting one or the other of the stakeholders seems to be rather secondary to what makes a given technology acceptable (or not).

Among others, the two useful factors which facilitate the acceptability of a new technology appear to be: projecting a good image and highlighting its benefits.

7.3.3 Conclusions and Recommendations for Societal Actions

The prospective approach we followed in this study regarding societal acceptability of territorial deployment shows that the public generally supports green technologies. However, several studies show the existence of a “social gap” between opinion polls and the acceptability of a territorialized deployment project: a public may be in favour of a type of energy but opposed to its deployment on its territory. In other words, acceptability does not only depend on the support or rejection of the innovation at a meta-level but also on the way the deployment project is intended in the territory:

- The emphasis on benefits and a fair distribution of benefits and costs promotes project ownership.
- The key is greater transparency and consultation in the project development, which could be implemented through transdisciplinary planning approaches together with discussions and mediations and public meetings with the population.
- The confidence level in the project is affected by the institutional or cognitive distance between the promoter and the locals, which could be lowered by co-construction or in other words by considering place attachment in regional or infrastructural planning and the conceptual involvement of the needs and wishes early in the process.

The psychological determinants of social acceptability study showed that, regardless of the technology, objective knowledge has little to do with the technology’s social acceptability, projected image, or associated benefits and costs and their perception. However, the image it conveys, as well as its associated benefits, seems to have a significant impact on its level of acceptability. More precisely, the more positive the public image of a technology and the more it is regarded as a source of benefits (particularly environmental benefits), the more likely it is to be

considered acceptable.

Among the studied technologies, Hydrogen fits this picture the most and is ahead of Green Batteries and Smart Grids (without the latter being considered negatively).

We therefore recommend working on the image projected by these technologies (particularly for Green Batteries and Smart Grids) and increasing the perception of their benefits. This will positively impact the population’s level of acceptability. Communication is key and has to be worked on (presentation format, graphic illustrations associated with technical elements, etc) (Bostrom et al., 2018; Hoffrage & Garcia-Retamero, 2018; Peters et al., 2006).

7.4 Environmental Impact

Life Cycle Assessment (LCA) is a comprehensive and standard methodology used to evaluate a wide range of environmental impacts that a product or service has over its whole life cycle, i.e., from cradle to grave, from raw material extraction, through manufacture and use, to waste disposal or recycling (see Fig. 7.7).

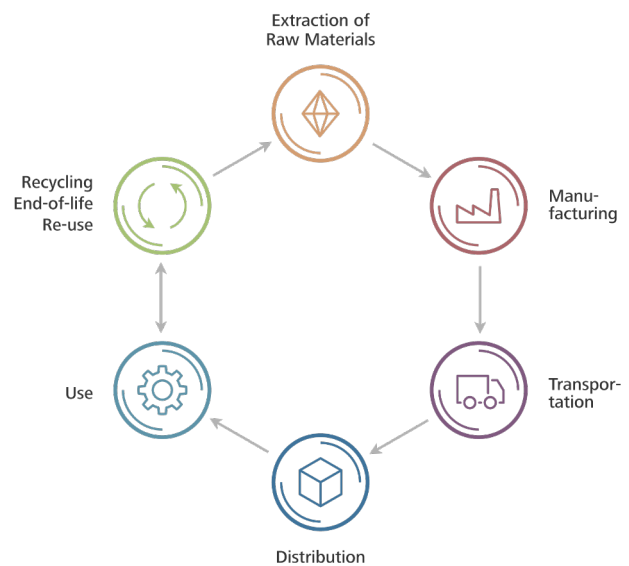


Fig. 7.7: Life cycle of a product

Each life cycle stage can be considered as a separate system and analysed using the LCA methodology. The data concerning the raw materials consumption and pollutants released to various environmental compartments are identified and quantified in the life cycle inventory analysis step. These data are converted into environmental impacts in the Life Cycle Impact Assessment step (LCIA). The purpose of LCIA is to express the impact in terms of category indicator, which is calculated by multiplying the

mass of emitted substances measured in the life cycle inventory with the fate factor (defined as the behaviour of the substances in water, soil, air medium and as so-called time residence of the substances) and the effect factor of the pollutants related to the studied system. In the following two studies, the choice was made to focus on the environmental impacts generated by the recycling phase of Li-ion batteries and the production of hydrogen. These two studies are to be linked to the pilot proposals made by the Li-ion battery recycling and the multimodal H₂ HUB subgroups. Present social, economic and environmental issues should be analysed for the sustainable development of a territory. It is relevant to quantify the environmental impacts of different Li-ion battery recycling scenarios as well as those of different hydrogen production scenarios in order to define those which are the least polluting and support the decisions of the various stakeholders.

7.4.1 Li-ion Battery Recycling

The growth in demand for Li-ion batteries makes it necessary to manage these batteries at the end of their life. This is essential to limit their environmental impacts. The environmental impacts assessment of Li-ion batteries recycling is the major scientific question of this subject; in order to quantify them the methodology of Life Cycle Analysis was used. The most widespread recycling processes on an industrial scale are pyrometallurgy, hydrometallurgy and mechanical processes. These make it possible to extract battery components at more or less basic levels. In many cases, a combination of these different processes is used (Fig. 7.8), but the choice of process(es) depends primarily on the materials to be recovered. The recycling process begins with a pre-treatment consisting of a mechanical process allowing the recovery of the main components (carcass, plastics, electronic components). This is followed by a thermal or chemical process, which will firstly remove the aluminium and copper sheets from the anode and the cathode respectively and secondly, improve the efficiency of the following treatment. This pre-treatment step can be likened to the first pilot planned by the battery recycling sub-group and entitled "Facility for the Dismantlement Batteries". The treatment of the electrodes promotes the recovery of the elementary components of the latter via pyrometallurgical or hydrometallurgical treatment. The battery recycling step corresponds to the pilot of the recycling sub-group entitled "Pilot Plant for the Recycling of Battery Materials".

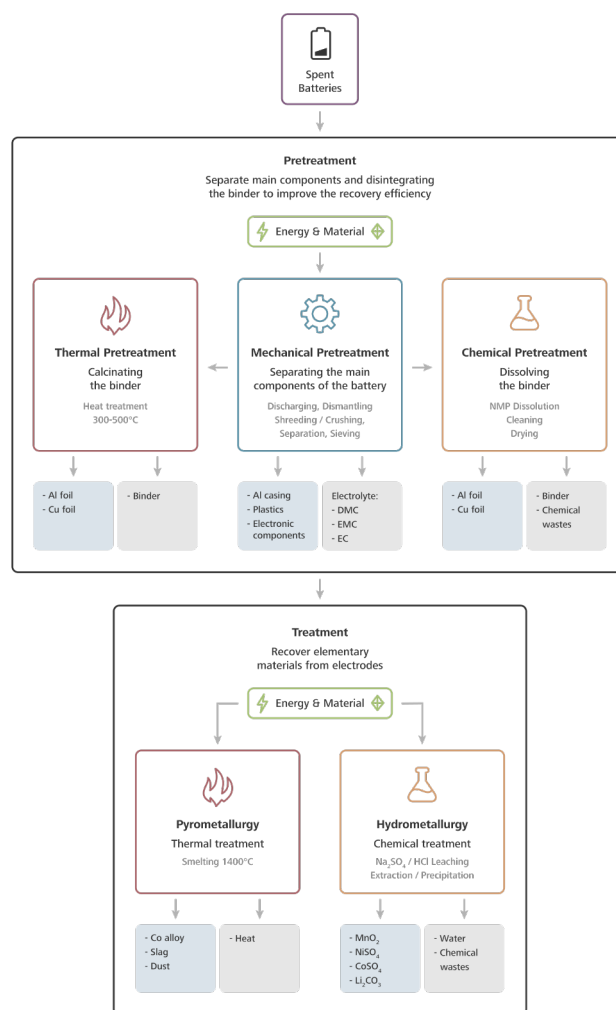


Fig. 7.8: Lifecycle boundaries of the studied system (Kautzmann et al., 2021).

A prospective Li-ion battery recycling LCIA was conducted using literature and the Ecoinvent database. We carried out the LCIA comparison of the recycling processes first independently for each recycling step (pre-treatment and treatment), then through four scenarios representing the possible combinations of elementary processes (Table 7.5). Both Scenario 1 and Scenario 2 consist of mechanical (M) and thermal (T) pre-treatments, but while Scenario 1's pre-treatment is then followed by a pyrometallurgy (P) treatment Scenario 2's pre-treatment follow up is a hydrometallurgy (H) treatment. Scenario 3 and Scenario 4, consist of mechanical and chemical (C) pre-treatments followed by a pyrometallurgy treatment for Scenario 3 and a hydrometallurgy treatment for Scenario 4. Evaluation of these scenarios will serve to assess the environmental performance of the recycling process that is envisioned by the Green Batteries Competence Group.

	PRETREATMENT			TREATMENT	
	Mechanical (M)	Thermal (T)	Chemical (C)	Pyrometallurgy (P)	Hydrometallurgy (H)
Scenario n°1	X	X		X	
Scenario n°2	X	X			X
Scenario n°3	X		X	X	
Scenario n°4	X		X		X

Tab. 7.5: Different scenarios for battery recycling process (Kautzmann et al., 2021).

The LCA study that was performed showed that (see Fig. 7.9):

- The impact on global warming expressed in equivalent CO₂ (the main contributors are Methane, Nitrous Oxide (N₂O), CFC-11, CFC-12, HCFC-22, HCFC-141b, HCFC-142b, HFC-134a and Sulphur Hexafluoride) is the most severe. In this impact category, it is preferable to opt for a hydrometallurgical treatment, which generates an impact two times lower than that of pyrometallurgy. The pre-treatment has little influence on the differentiation of scenarios in this impact category.
- On the contrary, pre-treatments have a strong influence on the use of energy from non-renewable sources. The energy required for chemical pre-treatment is up to twice the energy required for thermal pre-treatment. Indeed, the manufacture of the materi-

als used, in particular NMP (N-Methyl-2-Pyrrolidone), in the chemical pre-treatment requires a large amount of energy.

- Regarding the respiratory effects caused by inorganic substances, the thermal pre-treatment shows an insignificant impact compared to the chemical pre-treatment. On the other hand, hydrometallurgical treatment generates an impact two times lower than pyrometallurgy treatment in this impact category.
- The impact on carcinogenic effects and terrestrial ecotoxicity are very low compared to the other categories described above. However, we observe that hydrometallurgy has a greater impact on carcinogenic effects, due to the use of a large quantity of products harmful to human health.

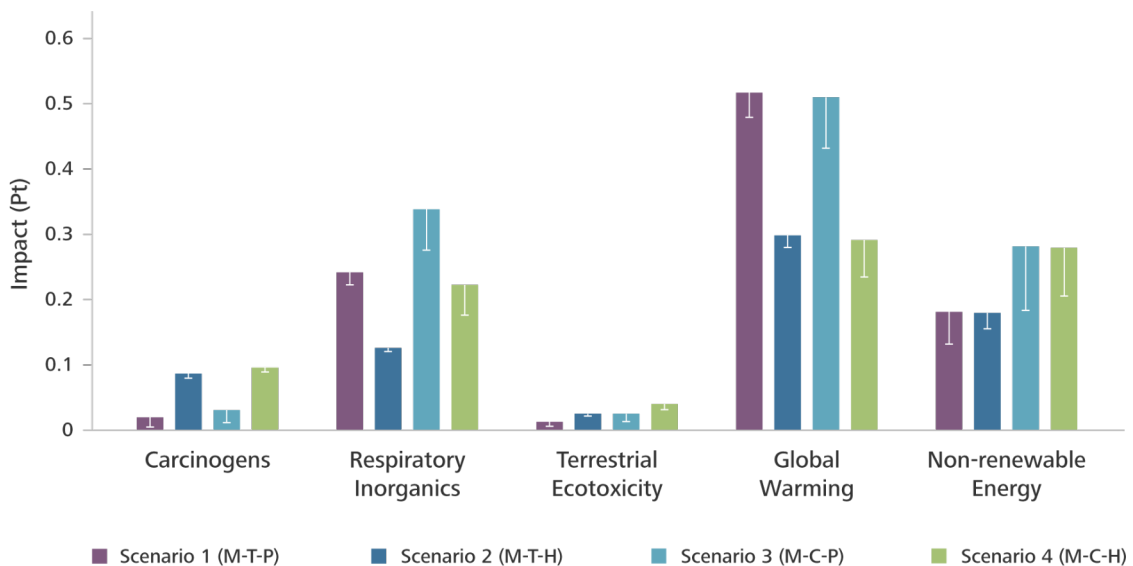


Fig. 7.9: Impacts of the different existing recycling scenarios for each identified category (Kautzmann et al., 2021)

Scenario 2, consisting of a mechanical then thermal pre-treatment and a hydrometallurgical treatment, therefore, seems to be the most efficient scenario from an environmental point of view, in any case, the best compromise given the categories of impacts considered. The detailed version of this study can be found in (Kautzmann et al., 2021).

ment and hydrometallurgical treatment, seems the most efficient from an environmental point of view and probably the best compromise taking into account the categories of impacts considered.

However, to date there is no properly established recycling process that would allow the simultaneous recovery

<p>Strengths</p> <p>The development of recycling contributes to securing the upstream of our industrial value chains in an integrated vision: it allows them to be complete in order to be stronger, more resilient and more competitive (CSF Mines et métallurgie, 2020).</p> <p>From an environmental point of view for</p> <ul style="list-style-type: none"> • pilot 1: "Facility for batteries dismantling", the best pre-treatment is mechanical, then thermal. • pilot 2: "Pilot plan for the Recycling batteries", the best treatment is hydrometallurgy 	<p>Weaknesses</p> <p>To date, the profitability of the lithium battery recycling activity is low, even negative. The development of this sector will remain dependent on many factors (recycling profitability, stationary energy storage needs, etc.) (CSF Mines et métallurgie, 2020).</p> <p>To conduct a complete LCA, industrial data is necessary but there is a lack of primary data. We consulted 63 papers and only 8 have been used to find data. Moreover, there is also a lack of data collected from companies, because of the problem of confidentiality.</p>
<p>Opportunities</p> <p>Collaboration with EDF and EURO DIEUZE companies or another recycling company could be an opportunity to implement a recycling unit on the Fessenheim site. A discussion concerning the supply and type of energy could take place and alleviate/compensate the energy-intensive aspect of the pre-treatment and treatment processes</p>	<p>Threats</p> <p>France has the assets to become the European leader in battery recycling, but is left behind by its European partners and its international competitors (CSF Mines et métallurgie, 2020)</p> <p>From a scientific point of view, the problem is related to the lack of data for conducting a sensitivity analysis.</p>

Tab. 7.6: SWOT analysis on Li-ion battery recycling.

7.4.2 Conclusions and Recommendations for Battery Recycling

The recycling of lithium-ion batteries is essential, to limit their impact on the environment if disposed of in landfills and to recover and reuse battery materials thus limiting the extraction of new ones. A life cycle analysis based on data from the literature made it possible to determine which scenario, i.e., which combination of these processes, is the most efficient from an environmental point of view. However, very little data is available because of the newness of these recycling processes and the confidentiality of the data (which is not shared by manufacturing companies). Moreover, because of the diversity of the existing processes, these data showed a strong variability which we took into account by using intervals of values for the data concerned. We have observed that scenario 2, consisting of mechanical and then thermal pre-treat-

of all lithium-ion battery components at attractive recovery rates (Zante, 2020; Mossali et al., 2020). The recycling processes presented here can be greatly optimised to reduce their environmental impacts. The recovery of the electrolyte could constitute a first major improvement but is to date only applied very infrequently on an industrial scale and the lack of data did not allow us to take it into account in this study. The use of citric acid ($C_6H_8O_7$) as a replacement for sulfuric acid (H_2SO_4) in the hydrometallurgy process could also reduce the environmental impacts of this process. However, this choice would be a detriment to the material recovery rate constituting the cathode. Finally, concerning the chemical pre-treatment, it is the production of NMP used in this step which is responsible for almost all of the impacts. The use of an alternative solution, such as sodium hydroxide (NaOH), could also be a solution to limit the impact of chemical pre-treatment, provided that its effectiveness in the disin-

tegration of the PVDF binder is comparable to that of NMP. New recycling technologies are also being developed, such as direct regeneration, which is a method of "repairing" the active material of the cathode (Li et al., 2017; Fan et al., 2021). This technology would thus make it possible to refurbish batteries without going through recycling and then produce new batteries from these recovered materials, which would constitute a shorter loop in the circular economy model. This very promising new technology would guarantee a significant reduction in environmental impacts because it requires lower amounts of energy and less materials than the conventional processes studied here. Finally, to facilitate battery recycling, the design of lithium-ion batteries can be redesigned. Research on the configuration of new "LEGO" type batteries (removable) is currently in progress and would make it possible to simplify the dismantling of these and dispense with the mechanical pre-treatment of crushing and separation (Tarascon et al., 2021).

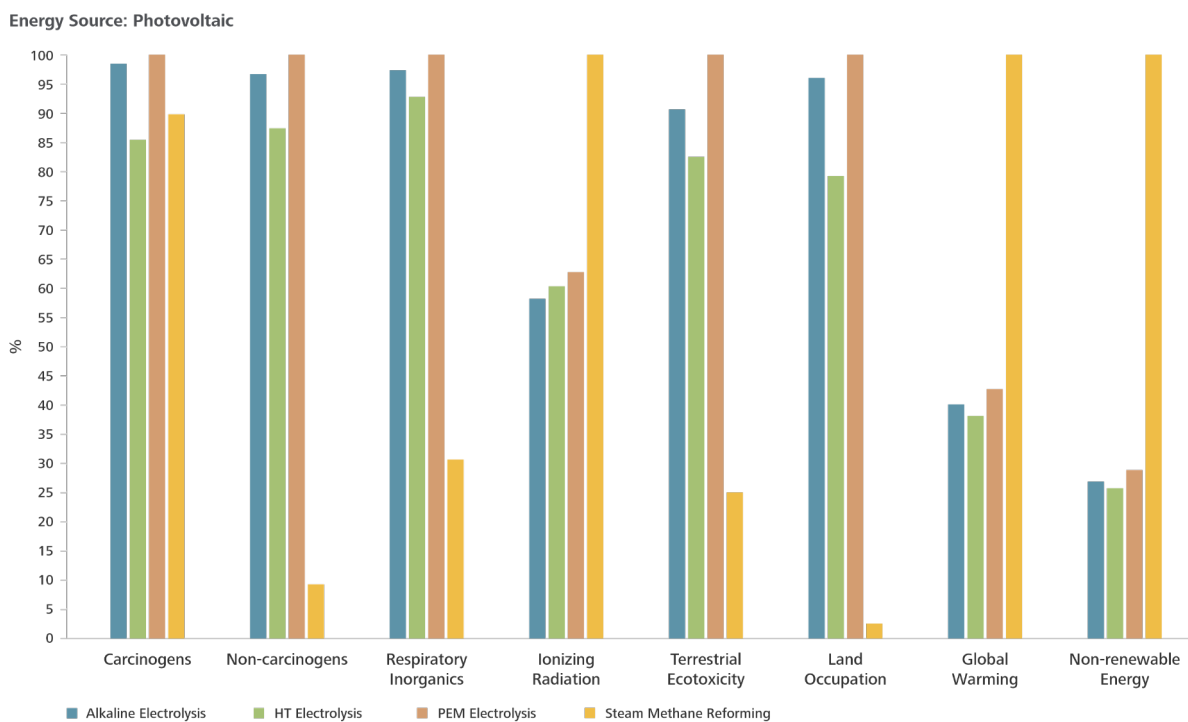
7.4.3 Hydrogen Production

The pilot project developed by the hydrogen group, named Multi-Modal H₂ Hub Neuf-Brisach, concerns the global life cycle of hydrogen as an energy vector, from its production to its use. Hydrogen production will be provided by a 20 MW electrolysis plant, located on the

banks of the Rhine and close to the Fessenheim hydroelectric plant. This electrolyser will be powered by a renewable energy source, perhaps delivered by a floating photovoltaic panel plant. Previous studies have shown that the operation phase and more specifically the electricity consumption during this stage is the main contributor to environmental impacts. However, gaps exist in these studies and are related to the absence of comparative analysis between the different electrolysis techniques as well as steam reforming over the complete life cycle and using different energy sources during operation.

Therefore, it seems necessary to develop comparative life cycle analyses between these different technologies in order to assess which process will have the least environmental impact. We then carry out a comparative LCA of the three main existing technologies: alkaline electrolysis, PEM (Proton exchange membrane) electrolysis and HT (high temperature) electrolysis.

In order to have a comparison reference, we include in this LCA; on the one hand, the current process mainly used for the production of hydrogen: steam reforming; and on the other hand, an energy source based on the French electricity mix for comparison to the photovoltaic energy source.



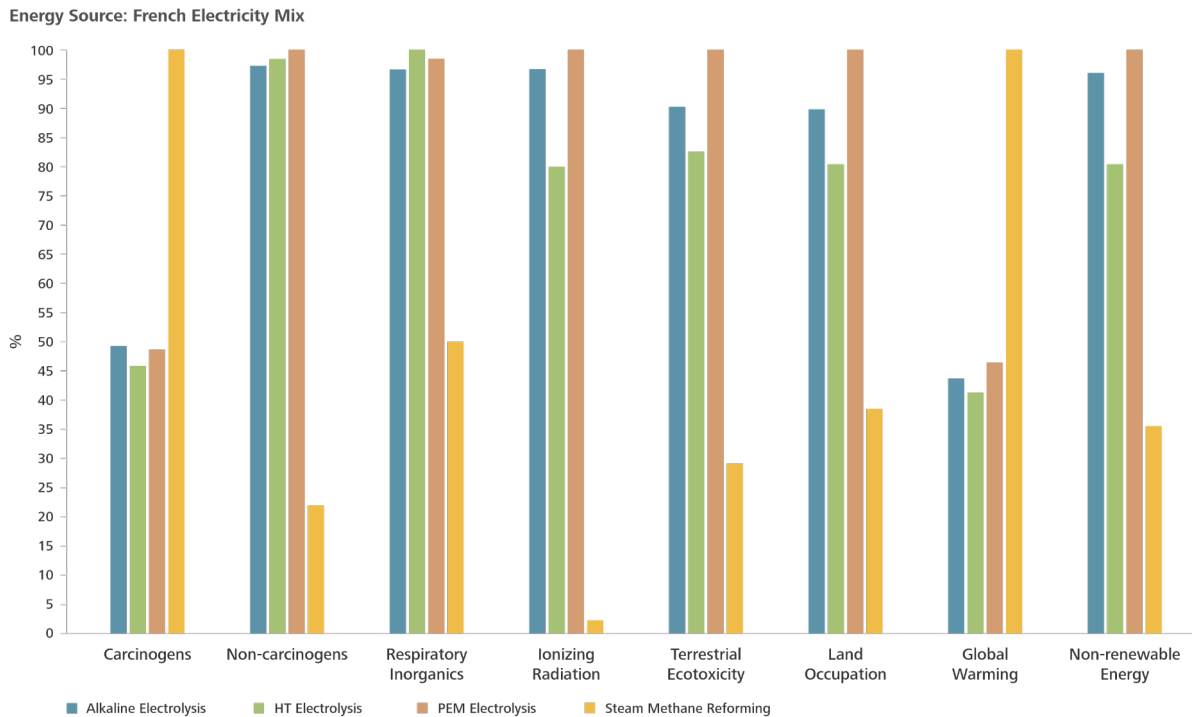


Fig. 7.10: Comparison of relative environmental impacts of steam reforming and electrolysis processes powered by: (top) a photovoltaic electrical source, (bottom) a mix-based on the French electricity mix (Dailland et al., 2021, pp.38-40).

The results, presented in Fig. 7.10 (top), show the comparison between the steam reforming process as well as the three electrolyser technologies: alkaline, proton exchange membrane, and high temperature electrolysis - whose operation is carried out by a solar energy source.

The first point that emerges from this analysis is the similarity of the different electrolysers from an environmental point of view. This equivalence comes mainly from the fact that a very large part of the impacts comes from the operating phase of the processes, which use the same energy source, with yields close to each other. The second point concerns the comparison to steam reforming. It is observed that this process exceeds (between 2 and 3 times greater) the environmental impacts of electrolysers on two indicators: global warming and the use of non-renewable energy. This difference is based on the processes for obtaining Hydrogen: one uses a renewable energy source and produces no pollutants during its operating phase, while the other uses a fossil energy source and emits large amounts of greenhouse gases. Steam reforming has similar or weaker effects on the other impact categories, apart from ionizing radiation emissions because SMR uses electricity for the operation of the infrastructure, based on the French energy mix comprising a large share of nuclear energy (emitting radioactive waste).

The results presented in Fig. 7.10 (bottom) show the same comparison of processes as in the previous scenario; this time the source of electrical energy during the operation

of the electrolysers was changed. This comparison shows once again the importance of the energy source for powering the electrolysers. The impacts concerning the use of non-renewable resources or ionizing radiation are reversed compared to the previous scenario in direct correlation with the French mix. Indeed, more than 70% of French electricity production (2019) is based on nuclear energy, directly responsible for the emissions of ionizing rays and the use of resources (uranium as fuel).

There is a very slight increase in the global warming indicator from electrolysers because although nuclear energy is practically carbon-free, there are still sources of electrical energy emitting GHGs in the French mix (8% via combustion natural gas, for example).

<p>Strengths</p> <p>The European Union, engaged in an energy transition aimed at decarbonizing the economy, rekindles the hope of a hydrogen society. The recovery plans of France and Germany provide for investments of several billion for the construction of a complete green hydrogen sector, from production to use, intended primarily for mobility</p> <p>If the electricity production of dihydrogen is done by electrolysis then this solution meets the climatic challenges, but only if the electricity production is carbon-free (renewable or nuclear)</p>	<p>Weaknesses</p> <p>However, the most widely used technique is steam reforming based on methane (CH₄). The mechanism consists of a double chemical reaction initiated at high temperature (between 840 and 950°C) strongly emitting CO₂</p>
<p>Opportunities</p> <p>Collaboration with GDS and EDF companies could be an opportunity to implement a hydrogen production unit on the Fessenheim site</p>	<p>Threats</p> <p>--</p>

Tab. 7.7: SWOT analysis on hydrogen production

7.4.4 Conclusions and Recommendations for Hydrogen Production

The results of this study showed that there was some similarity between the impacts of the different technologies, but that high-temperature electrolysis offered a better environmental compromise, especially if the infrastructure is supplied by a network of steam already present on an industrial site. This process is then followed by alkaline electrolysis and finally by PEM electrolysis.

The study also showed the relevance of producing Hydrogen by electrolyzers rather than by the traditional process of steam reforming, particularly with regard to greenhouse gas emissions. Indeed, the primary goal of the feasibility study is the development of a carbon-neutral region on the territory of Fessenheim and its surroundings.

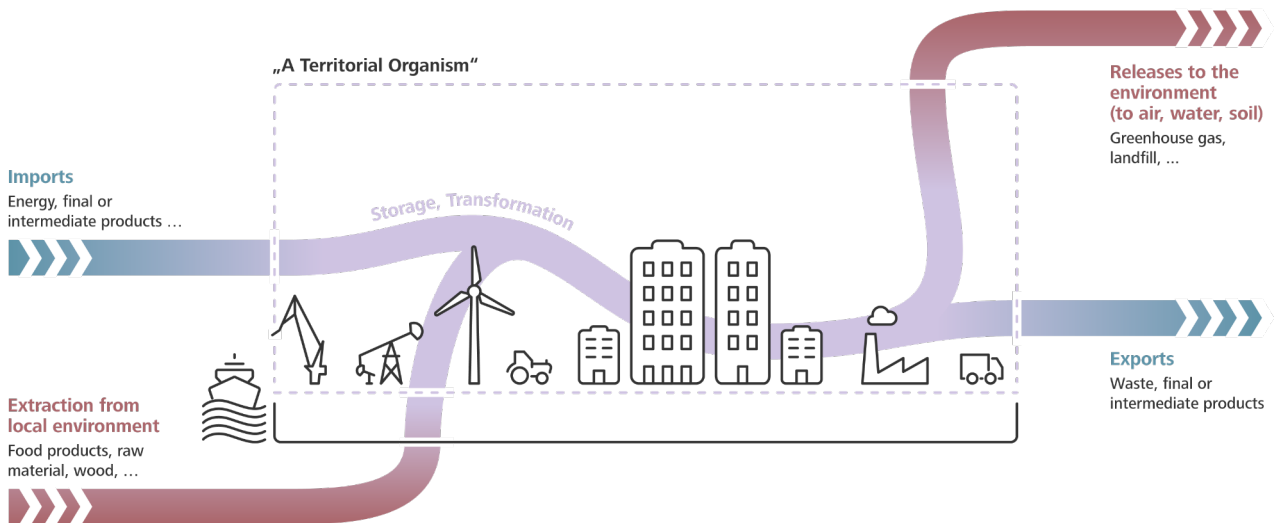


Fig. 7.11: Concept of metabolism applied to a territory – a frame to describe physical flows in link with the economy (Ribon et al., 2018)

7.5 Territorial Metabolism

The territorial metabolism approach describes physical flows (material, energy, persons) involved in the economy of a territory (see Fig. 7.11). This approach is complex because it is global and systemic, while the available data is limited, but it opens the way to various applications (Ribon et al., 2018). Among other things, it will allow researchers to identify local resources and needs; supervise energy, mobility, and material flows; assess environmental impacts; build a shared vision of the territory; and improve regional planning. Studying the territorial metabolism of the Fessenheim area will provide a vision of flows linked to the pilot projects, an opportunity to question their relevance and their territorial anchorage.

7.5.1 Overview

Five themes relevant to the pilot projects were taken into consideration: mobility, energy and climate, hydrogen industrial ecosystem, raw and critical materials, and land use. Public and area-specific data sets have been collected and analysed to provide an overview for each theme. The purpose is to highlight the issues linked to the territorial flows and resources, in connection with the pilot projects. Key elements of the analysis are summarized in the form of a SWOT analysis for each pilot project (Tables 7.8, 7.9 & 7.10). Each theme is further developed and discussed in the following sections to support our analysis.

1 Green Batteries	
<p>Strengths</p> <p>The growing market of batteries (electrical cars, embedded systems) is high. Managing batteries in their end of life will thus become crucial (from logistic, toxicity and resource preservation points of view). 2nd-life approach is particularly interesting for efficient resource use, especially regarding critical materials / rare earths (nickel and lithium).</p> <p>Carnot batteries seem particularly interesting for re-using Fessenheim power plant infrastructures that already include hydro-systems (cooling, pool, pumps, etc).</p> <p>Even with new emerging technologies, Lithium-ion batteries (LIB) are probably the most mature technology standard for the next few years. Massive amounts of end-of-life LIB are thus expectable in the future.</p>	<p>Weaknesses</p> <p>Electric cars represent only 0,4% of all cars in 2019 in Haut-Rhin (1743 vehicles). Even with the current high growth rate (+30%/year), that would take years (probably 5 to 10) before having significant amounts of batteries for 2nd-life or recycling.</p>

<p>Opportunities</p> <p>Some of the pilot projects may have synergies to also manage other battery technologies or sizes (thermic car, smartphone, inverter, etc).</p> <p>Batteries in their 2nd-life could be associated with a hydrogen electrolyser pilot project for better load-shedding.</p> <p>The Fessenheim site may be more interesting for the battery industry than for hydrogen, since the product is much more easily transportable (it does not need the location where it will be used to be close to the production location).</p> <p>The Rhine may be used for a low-carbon product transportation. Different components of the green battery industrial ecosystem might be located near the Rhine and connected through it.</p> <p>Pilot projects may contribute to reinforcing norms on batteries, especially regarding standard compatibility (functioning point, size, structure). This is necessary to improve reusability and recyclability of the next battery generations.</p> <p>Primary resources deposits for battery technologies are available in the territory (for example Nickel deposit around Kruth, or lithium project in Bruchsal). However, the potential synergies between this resource exploitation and the project have not been studied yet.</p>	<p>Threats</p> <p>Upstream weak acceptability due to a rebound effect linked to the exploitation of scarce resources whose availability is by definition limited</p> <p>Energy dependency: threat of blackout due to growing demand for electricity</p> <p>The tolerance for the installation of this type of plant: potential pollution from a battery recycling plant is likely to affect the cost-benefit ratio</p>
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Tab. 7.8: SWOT Analysis related to Green Batteries

2 | Hydrogen

Strengths

Neuf-Brisach (FR) / Breisach am Rhein (DE) and Ottmarsheim (FR) / Neuenburg am Rhein (DE) are the best locations for H₂ multi-hub development around Fessenheim (especially on the French side) since they offer multiple possible H₂ applications: industrial, mobility (truck/boat/train), power-to-gas, high electrical power available for electrolysis.

Some of the industries already present on these sites are among the highest-CO₂ emitters of the territory. Development of a hydrogen solution may result in significant reduction of GHG emissions for these industries.

Coupling electrolysis with photovoltaic panels may help to reduce the electrical load during some days, in a counter-cyclical way.

Weaknesses

Since the closing of the Fessenheim power plant, the territory is no longer self-sufficient when it comes to electricity consumption (only 2/3 self-sufficiency in Haut-Rhin). H₂ production through electrolysis without associated electricity production means will increase the territorial dependency on external supply.

The profitability of the electrolysis process depends on a high load factor. Thus, the process is not suitable for regulating intermittent sources of energy. Also, the electrolysers cannot work in only a counter-cyclical way (e.g., during cloudy/winter days, at the 7pm-peak).

The site of Fessenheim gathers less potential local H₂ applications than the two previously mentioned ones. It may not be relevant to focus on it in the project.

Few industries (at most 10) in Haut-Rhin are currently using H₂ in their process. Industries that could benefit from integrating H₂ in their process are unknown. Most of the market development will probably lean on mobility usage.

The economic model of H₂ systems and ecosystem remains uncertain, especially with electricity price volatility.

No mention of coordination with regional strategy.

OPPORTUNITIES

Vynova PPC industry (Vieux-Thann) should be considered in the H₂ industrial ecosystem of the territory.

Services areas are locations designed for a Truck Hydrogen Fuel Station (HFS). Economic and LCA scenarios must identify if it is better to produce hydrogen onsite with electrolysers or to mutualise production capacities (through the pilot) and deliver the stations by truck.

The Hydrogen train line from Breisach to Colmar could be extended to Metzeral.

THREATS

Growing market for H₂, especially for mobility, is still hard to evaluate. Political incentives and territorial coordination are necessary for securing fast market development.

Many H₂ technologies are using platinum, which is a very rare metal. Availability and price volatility may affect the sector.

Tab. 7.9: SWOT analysis related to Hydrogen.

3 Smart Grids	
<p>Strengths</p> <p>The development of intermittent renewable energies requires more advanced management of the electrical network.</p>	<p>Weaknesses</p> <p>Poor current knowledge of the electrical needs of the planned projects. Accurate data (with little time step) is needed to give an overview of the actual consumption and production and to assess the benefits of the project.</p> <p>Several storage technologies needed for implementing resilient smart grids over several days (for example through power-to-gas-to-power) are still in development.</p>
<p>OPPORTUNITIES</p> <p>Green batteries project can offer solutions for electrical network stabilisation.</p> <p>H₂ production through electrolysis is controllable and contributes to energy storage techniques.</p> <p>Project should contribute to open accurate data concerning a real case, to feed other similar projects.</p> <p>Electrical vehicles can offer a means of flexibility.</p>	<p>THREATS</p> <p>H₂ production through electrolysis requires a significant period of operation to be economically viable. This could be incompatible with the high intermittency of solar and wind generation.</p> <p>The effectiveness of smart grids also relies on efficient sobriety actions and behavioural changes, which can be difficult to achieve.</p> <p>Electrical vehicle development requires more electricity.</p> <p>Data communication through the grid is very critical. Protection against malfunctions and hacking is extremely important.</p>

Tab. 7.10: SWOT analysis related to Smart Grids.

7.5.2 Territorial Mobility

Four graphics were used to structure the analysis on the opportunities around Fessenheim for de-fossilised mobility (see Figs. 7.12, 7.13, 7.14 & Tab. 7.11).

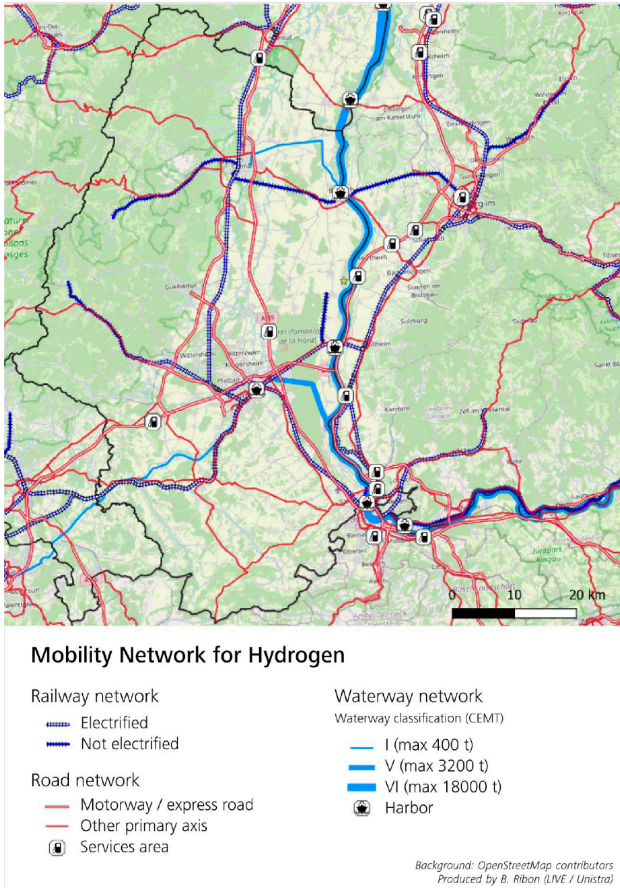


Fig. 7.12: Map of transportation networks: railway, road, waterways. Data sources: SNCF, Deutsche Bahn, OpenStreetMap, Karto-District.

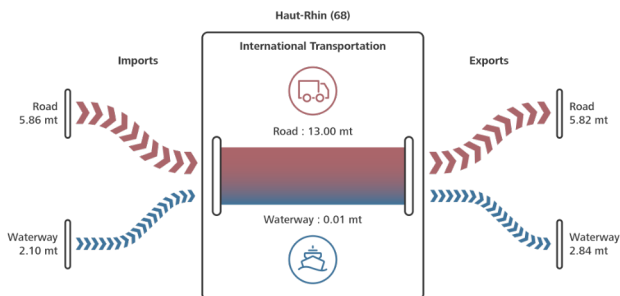


Fig. 7.13: Merchandise transportation into Haut-Rhin (by waterway and road, data for railway are unknown). Source: SitraM 2018 from Ministère de la Transition Écologique.

Registration of new Personal Cars (Haut-Rhin)

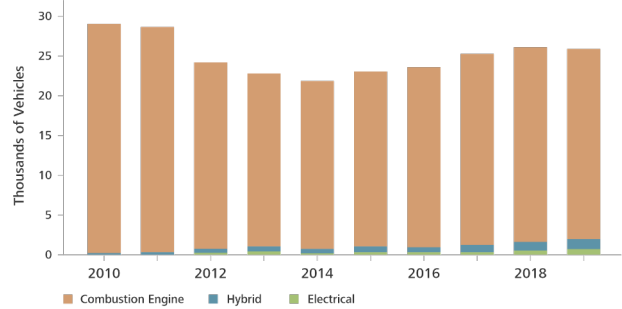


Fig. 7.14: Evolution of the motorisation of new cars in Haut-Rhin. Data source: Données sur les immatriculations des véhicules from Ministère de la Transition Écologique.

New car registration [vehicles / 1000 cap.]	2019		2020	
	BEV (% of all cars)	All cars	BEV (% of all cars)	All cars
Grand Est 5 550 000 cap.	3 169 (1,8 %) [0,6]	171.637 [31]	9 034 (7,0 %) [1,6]	128 177 [23]
Haut-Rhin 761 500 cap.	635 (2,5 %) [0,8]	25 829 [34]	1 528 (8,3 %) [2,0]	18 362 [24]
Baden-Württemberg 11 070 000 cap.	10 223 (2,0 %) [0,9]	518 851 [47]	31 367 (7,4%) [2,8]	425 503 [38]

Tab. 7.11: Evolution of the motorisation of new cars in Grand Est and Baden-Württemberg. BEV: battery (only) electrical vehicle (MTE-DES, Statista).

7.5.2.1 Waterway Infrastructure

The Rhine is a structural as well as cultural infrastructure for the territory. A significant amount of merchandise is transported by boat (almost 5 million tons per year), mainly oil products, cereals, gravels, and containers. The Rhine connects the territory directly to neighbouring countries (Germany, Switzerland), Belgium and the Netherlands; this gives access to global maritime transportation. Thus, the Rhine should be considered as a focus for innovation within the territory. However, also a connection to the harbors of Marseille and Genoa is possible in multi-modal mode using railway connection.

As far as the hydrogen hub pilot project is concerned, “hydrogenification” of boats seems to be an interesting specific direction, both for developing the motorisation technology and for installing H₂ fuel stations in different harbours along the Rhine.

Regarding the second life battery pilot project, the Rhine can be used for a part of the material logistics - assuming the recycling plant is located close to the river.

7.5.2.2 Railway Infrastructure

Few railway lines in the territory are not yet electrified. They are good candidates for hydrogen-powered trains:

- Thann – Kruth (FR): extension of the already electrified line Mulhouse – Thann
- Metzeral – Colmar & Colmar – Neuf-Brisach (FR)
- Freiburg im Breisgau – Breisach am Rhein (DE)
- Freiburg im Breisgau – Elzach (DE)
- Basel – Erzingen (CH-DE)

Additionally, the presence of a train technical center in Mulhouse, where an H₂ fuelling station can be located is

also noted. There are already plans to run hydrogen trains on the Mulhouse – Thann – Kruth line at the end of 2023 (SNCF, 2021). In parallel, there is a project to electrify the Freiburg im Breisgau – Breisach am Rhein line (Frietsch-Schöneberg, 2019). It could be interesting to consider running an H₂-powered train on the other lines and have an H₂ fuelling station on the German side as well.

7.5.2.3 Road Infrastructure

The development of hydrogen mobility seems to be more adapted for heavy vehicles (trucks) than light ones (cars). Thus, hydrogen fuelling stations are ideally located near main transport axes or industrial areas - service areas being premium locations. There are only 3 on the French side, and 9 on the German side. Hydrogen fuelling stations in industrial areas in synergy with other applications (like in Ottmarsheim and Neuenburg am Rhein) are also interesting locations.

Furthermore, it would be interesting to have a life cycle and economic analysis to compare these two possibilities: producing H₂ on-site (on service area) with an electrolyser (for example) or producing hydrogen somewhere else with more capacity (economy of scale) but having to transport it to the service area where the only concerns would be hydrogen storage and truck distribution.

7.5.2.4 Electric Mobility

Data on motorisation of new registered personal cars show a slowly growing trend towards electric mobility though this is still limited to a small proportion of vehicles (less than 10 %). Even with a very significant increase in electric cars sold in 2020 (+150% compared to 2019), they will become mainstream only in a few years from now. With an 8-year battery lifetime, we do not expect a significant quantity of batteries to be recycled before at least 2030.

The installation of recycling capacity must take this time horizon into account. However, for a pilot project with a low target capacity (1 ton of battery/day i.e., around 2 or 3 cars) designing innovative recycling infrastructures and testing the process under real conditions is needed. In the long-term (i.e., at least 15-20 years), we evaluate that around 120 000 BEV could be sold each year in the Upper Rhine (~20 vehicles/year/1000 capita). Another study also comes up with similar estimates (Neff et al., 2021). With two battery sets for one vehicle (vehicle lifetime is around two times battery lifetime), that would represent around 250 tons per day of battery to be recycled. These figures are speculative, but still credible and provide a first proposal of a long-term target.

7.5.3 Energy and Climate

Energy Production and the associated infrastructure are vital components that must be discussed further with regards to the climate. The transition in energy carriers has a strong impact on the climate and relevant technologies, as well as their usage are at the heart of this subchapter.

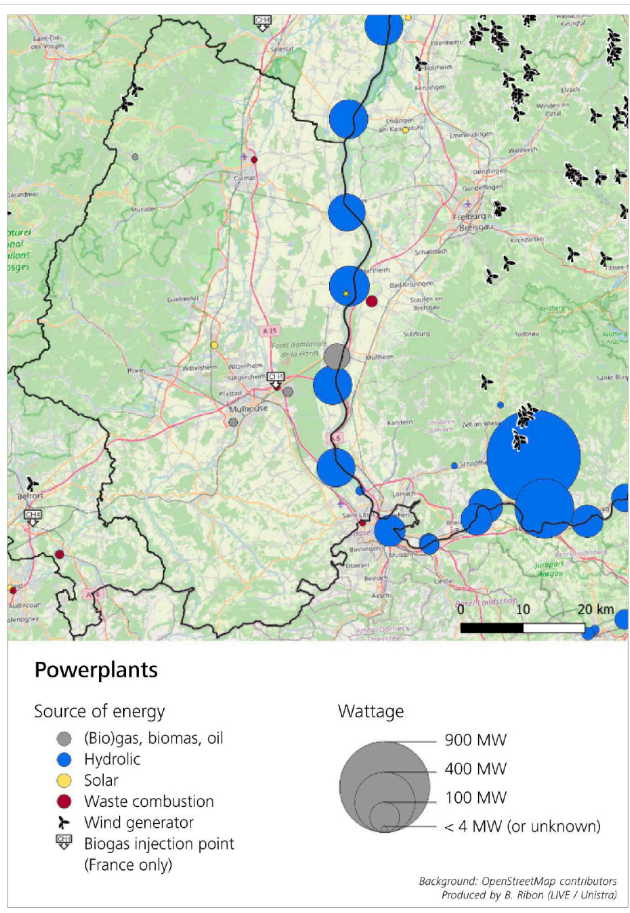
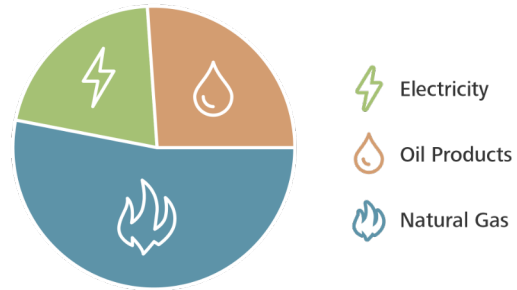


Fig. 7.15: Map of hydropower plants in the area. Data source: OpenStreetMap contributors

7.5.3.1 Electricity Production and Consumption

Since the closing of the nuclear power plant of Fessenheim, the main source of electricity in the territory comes from the Rhine thanks to the presence of the numerous installed hydroelectric dams (Fig. 7.15). But this is not sufficient to cover the electricity demand (see Figs. 7.16 & 7.17). Thus, the territory is dependent on other sources and/or external supply. We also show energy price index evolution over the last three decades (Fig. 7.18) to bring more contextualisation elements.

Consumption Haut-Rhin (68) - 2018 (Total : 27.8 TWh)



Resulting CO₂ Emissions (Total : 5.9 mt eq. CO₂)

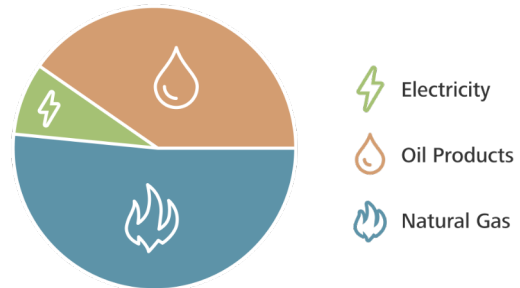
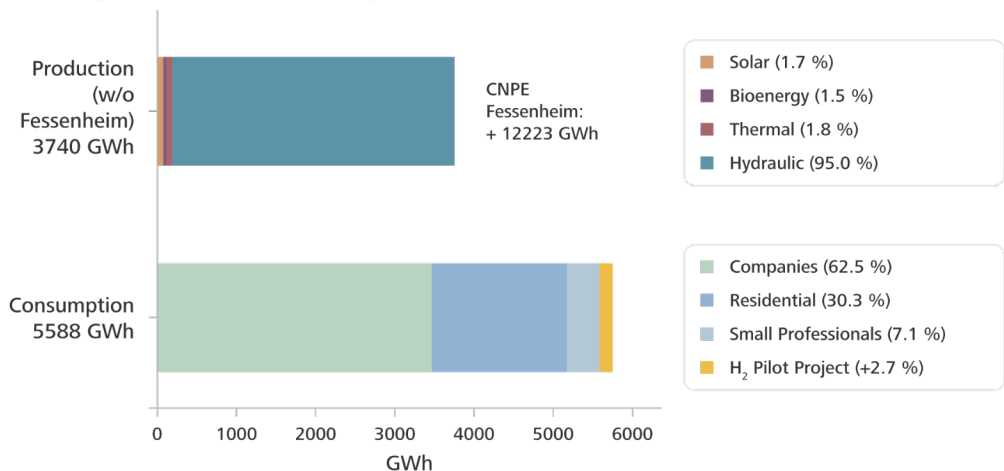
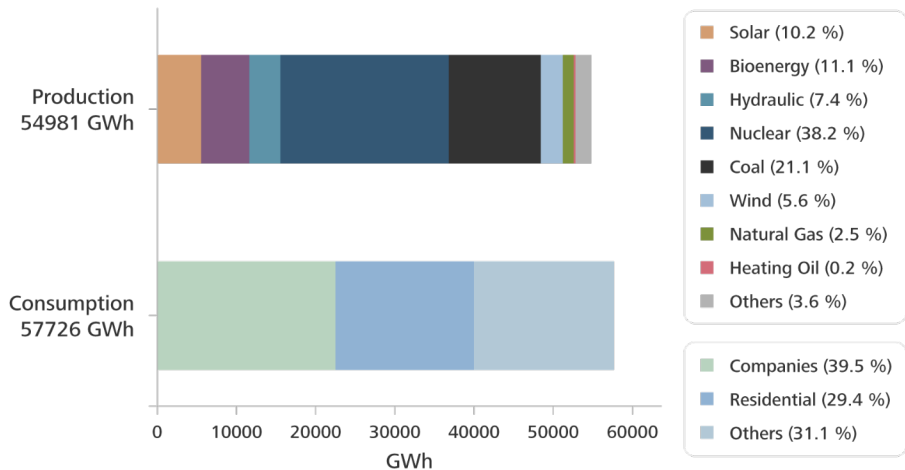


Fig. 7.16: Energy consumption in Haut-Rhin (top), and resulting CO₂ emissions (bottom). Data source: Données locales de consommation d'énergie from Ministère de l'écologie.

Electricity Production and Consumption (Haut-Rhin) - 2019



Electricity Production and Consumption (Baden-Württemberg) - 2019



Electricity Production and Consumption (Grand Est) - 2019

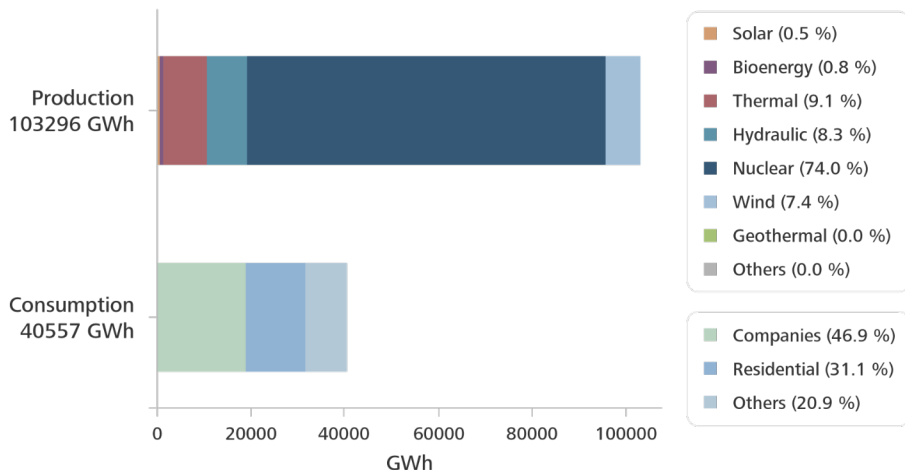


Fig. 7.17: Electricity production and consumption in Haut-Rhin (top), Baden-Württemberg (middle) and Grand Est (bottom). Data sources: Données locales de consommation d'énergie from Ministère de l'Ecologie ; Erzeugung und Verwendung from Statistisches Landesamt Baden-Württemberg ; MUKEBW 2019.

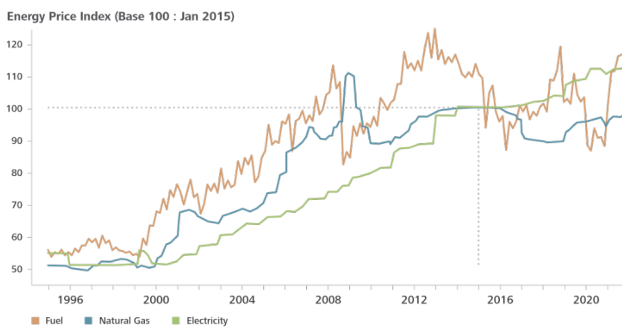


Fig 7.18: Energy Price index evolution in Baden-Württemberg (base 100: january 2015). Source: Erzeugung und Verwendung from Statistisches Landesamt Baden-Württemberg.

Taking into account the fact that there is an energy production deficit in the Upper Rhine region, the production of hydrogen through electrolysis does not look like the best choice, as it would increase external dependency. The complementary installation of photovoltaic panels can, however, contribute to balancing the project in this regard.

In the territory, there is a lot of agricultural activity making it favourable for the production of biogas through methanisation. It thus looks very interesting to explore the possibility of producing hydrogen from biogas. This is already possible with current steam reforming and emerging thermo-cracking techniques, which allow the production of hydrogen with a negative climate impact (see Section 7.5.4). However, biogas production is more space consuming, and around 20 methanisation plants are needed to get power equivalent to that of the H₂ pilot project.

7.5.3.2 Electrical Smart Grids

The electricity network requires a permanent balance between production and consumption. With the development of renewable energies, this balance is more difficult to achieve because the control of intermittent production means is not possible. A combination of different strategies is therefore needed to ensure the balance. It can consist in building back-up power plants, developing storage installation, as well as shifting and reducing needs.

- Back-up production means are controllable power plants running only when other means are not producing enough. Usually, they are fossil gas power plants. It is possible to use biogas if available to reduce climate impact, but with a low load factor and in a transitional process, even using fossil gas may be worth looking at the given service.
- Storage techniques for electricity are in permanent improvement. Lake dams are currently widely used, but most of the interesting sites are already ex-

ploited, thus their future development is unlikely. Thermal and electrical batteries, power-to-gas-to-power (through H₂ or CH₄), and pressured air are emerging technologies that may reinforce the storage capacity.

- Shifting the need may concern, for example, the use of domestic hot water or the electrical vehicle load: their operation can be shifted from running during consumption peaks without affecting the user (if some precautions are taken). Examples of a few days shifting are more difficult to find. Probably some need could be shifted from the weekdays to the weekend.
- Reducing the need is probably the most important approach to bring resilience and climate neutrality to the electrical networking. It mainly consists of isolating buildings, reducing individual car need, reducing good manufacturing, removing permanent screens, improving light efficiency etc... but this may also concern processes (especially industrial ones) that could come to a halt when demand is much higher than supply.

Based upon these strategies, an advanced control system is necessary to arbitrate which means to operate and which to stop or shift. But this control system is not by itself sufficient. It must be built upon existing energetic installations and adapted social organisations to be efficient. Thus, we suggest including in the project a thorough examination of the technical and social means available to implement the strategies outlined above.

7.5.3.3 Reducing CO₂ Emissions in Industry

Some of the biggest CO₂-emitters in the territory are hydrogen users. Hydrogen is currently produced by natural gas steam reforming, which generates considerable CO₂ emissions (see Fig. 7.19). Having low-carbon H₂ production for these industries may result in significant reductions of these emissions. Undoubtedly, this study is an important activity to reach the target of a neutral-CO₂ territory.

7.5.4 Hydrogen Industrial Ecosystem

Electrolysers are not the only technology used to produce green hydrogen, even if other technologies may be less technically mature. Tables 7.12 and 7.13 give an overview of hydrogen production possibilities and applications respectively. Hydrogen plants currently running in Haut-Rhin can be seen in Fig. 7.20 and listed in Tab. 7.14. Based on this data, the current state of hydrogen uses, production, and needs are discussed.

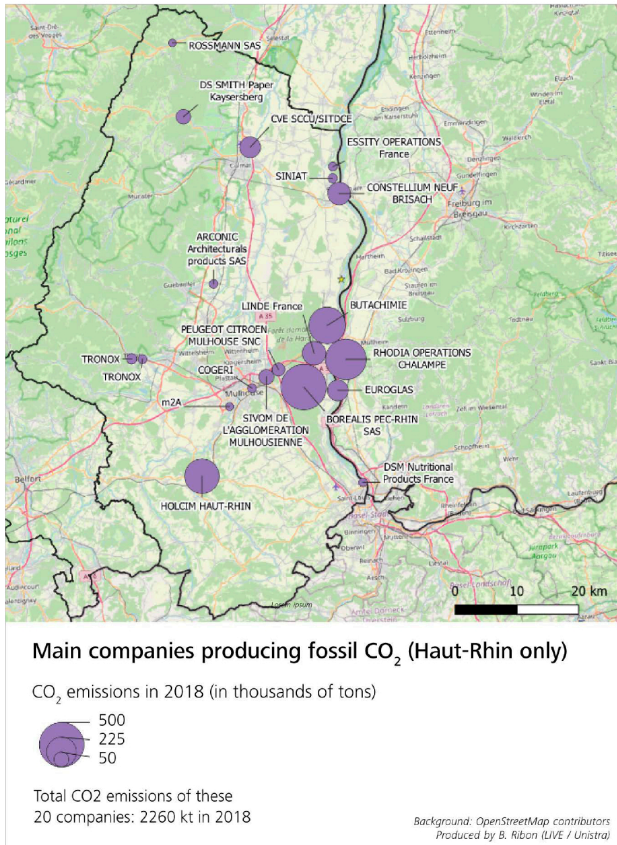


Fig. 7.19: Map of the main fossil CO₂ industrial emitters in Haut-Rhin. Data source: IREP-Registre des émissions polluantes from Ministère de l'Ecologie.

Process	Significant reactant of the process	Significant co-product of the process	Comment
Industrial co-product			Concerns industrial plant where hydrogen is coproduced in some process. This hydrogen is sometimes released in the air if there is no use. Vynova PPC (in Vieux-Thann) is in the case.
Electrolysis	Electricity ; (heat*) ; pure water	O ₂	The plant may require high power supply (20 Mw-for pilot project) *Heat is needed for high-temperature electrolysis technology (not for all electrolysis technologies)
Steam reforming		CO ₂	Biogas can also be used in order to reduce climate impact
Biomass thermolysis		(CH ₄) ; CO ; biochar	May have a negative climate impact on the life-cycle
Production through biological process	Organic waste		Near organic waste producer See Menia et al. 2019.
Thermo-cracking	CH ₄	Solid carbon	May have a negative climate impact if biogas is used

Tab. 7.12: Overview of hydrogen production means.

Application	Significant co-reactant of the process	Significant product of the process	Comment
Industrial input (refining, fertiliser, ...)			Few industrial sites are using H ₂ in their process (around Ottmarsheim, Marckolsheim and Sélestat)
Mobility and mobile machines			Hydrogen Fueling Station – HFS should be placed near mobility network (main road, H ₂ railway, river) or be accessible to mobile machines (e. G. For agriculture)
Gas network injection			Currently limited to 6% of H ₂ in gas network (in France) but it may increase up to 10 or 20 % in the future
Methanation	CO ₂	CH ₄ ; heat	Ideally placed near a gas network, a CO ₂ producer and a heat network
Spacecraft			No concern for the project

Tab. 7.13: Overview of hydrogen applications.

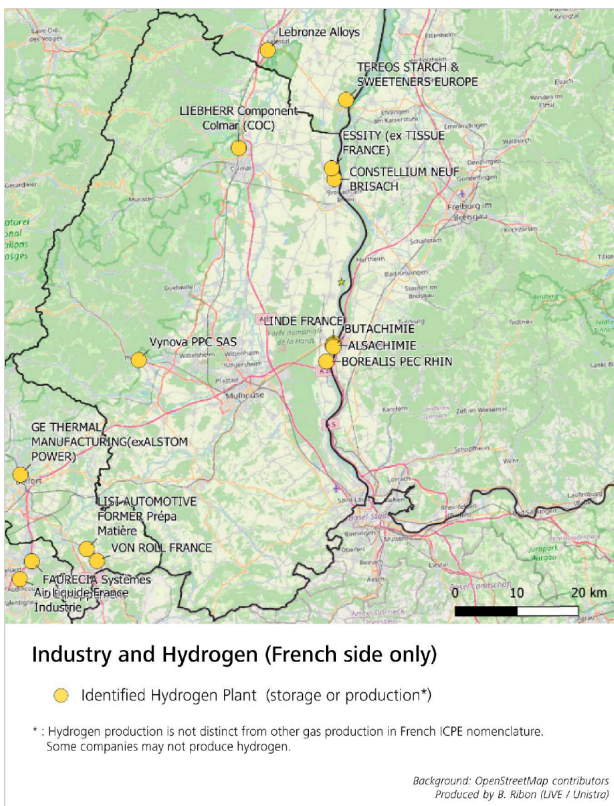


Fig. 7.20: Map of hydrogen plants in Haut-Rhin (storage or production). Data source: ICPE-Registre des installations classées 2019 from Géorisques.

Code	Nom	Activity	City	ICPE details	ICPE nomen.
0067.0 0433	Vynova PPC SAS	Fine chemistry of bromine, potassium and chlorine derivatives	Vieux-Thann	H ₂ production: 6 t/j	Ex-1415; 3420-a*
0067.0 0469	CONSTELIUM NEUF BRISACH	Aluminium sheets, coils and strips	Biesheim	H ₂ storage: 24,5 kg	1416
0067.0 0471	BOREALIS PEC RHIN	Chemicals and fertilizers	Ottmarsheim	Gas production: 775	3420-a*
0067.0 0513	BUTACHIMIE	Polyamide intermediates of the nylon chain	Chalampé	Gas production: 33	3420-a*
0067.0 0538	ALSACHIMIE	Production of polyamide and nylon intermediates	Chalampé	Gas production	3420-a*
0067.0 0642	ESSITY (ex TISSUE FRANCE)	Manufacture of toilet paper, single-use tissues	Kunheim	H ₂ storage: 50 kg	Ex-1416
0067.0 0643	TEREOS STARCH & SWEETENERS EUROPE	Processing of wheat and maize into starches and derived sweetening ingredients	Marckolsheim	H ₂ use or storage max on site: 3 t	4715-1
0067.0 0787	Lebronze Al- loys	Casting, rolling, drawing and coating of copper alloys	Sélestat	H ₂ Storage: 0,45 t	Ex-1416
0067.0 2200	LINDE FRANCE	Manufacture of industrial gases	Chalampé	H ₂ production max on site: 1,16 t	3420-a
0067.0 5541	LIEBHERR Component Colmar (COC)	Design of high-performance diesel engines	Colmar	H ₂ storage: 9,2 kg	Ex-1416

Tab. 7.14: Hydrogen plants in Haut-Rhin (storage or production⁴). Data source: ICPE-Registre des installations classées 2019 from Géorisques.

⁴ Hydrogen production is not distinct from other gas production in ICPE nomenclature. Quoted companies may not be hydrogen producers.

7.5.4.1 Hydrogen Use in the Territory at the Present Time

Currently, hydrogen is used in a few locations in Haut-Rhin (see chapter 5.4). In Vieux-Thann, Vynova PPC is producing H₂ as a by-product of its processes. This H₂ is currently partially released in the air, but a project is ongoing to recover it. At the other industrial site, H₂ is used as a reactant for processes. Currently it is mainly produced from natural gas steam reforming.

Using biogas could significantly reduce climate impact without the need of new technologies development and costly infrastructure.

7.5.4.2 Hydrogen Price

Electricity prices have been particularly volatile in recent months but have also shown a significant upward trend

over the past decade (Fig 7.18). These prices represent a significant part of the cost of producing hydrogen by electrolysis. Basic calculation shows that H₂ production with current technology would need a carbon price of at least 200 €/ton of CO₂ to be competitive. With the price peaks we have seen this winter, the threshold could even be higher.

7.5.5 Raw and Critical Materials

Raw materials are an important concern for new energy-related technologies. Among these materials, some are common (iron, aluminium, copper) and others are scarcer (nickel, manganese, cobalt and lithium for batteries, platinum for hydrogen electrolyser). Below, you will find some summary elements for a better understanding of the related issues (see Figs. 7.21 & 7.22, Tabs 7.15 & 7.16 and following discussion).

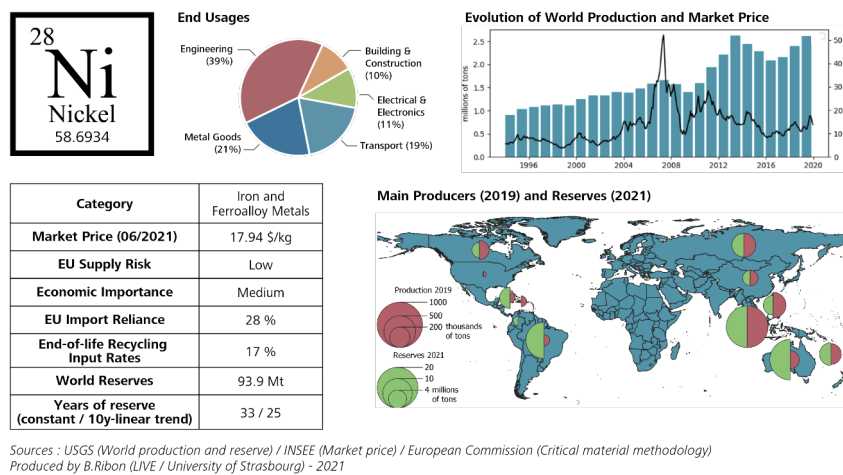


Fig 7.21: Datashheet for Nickel. Data sources: USGS (World production and reserve); INSEE (Market price); European Commission (Critical material methodology).

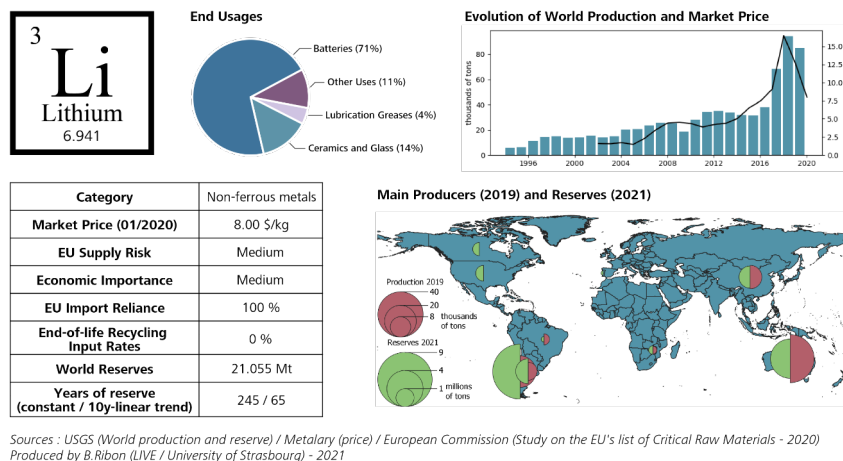


Fig 7.22: Datashheet for Lithium. Data sources: USGS (World production and reserve); Metalary (price); European Commission (Study on the EU's list of Critical Raw Materials - 2020).

kg/kWh	Li	Ni	Co	Mn
NCA	0,10	0,67	0,13	0,00
NMC 111	0,15	0,40	0,40	0,37
NMC 433	0,14	0,47	0,35	0,35
NMC 532	0,14	0,59	0,23	0,35
NMC 622	0,13	0,61	0,19	0,20
NMC 811	0,11	0,75	0,09	0,09
LFP	0,10			

Notes: NCA refers to nickel cobalt aluminium oxide, NMC refers to nickel manganese cobalt oxide (numbers indicate the atomic share of each metal), LFP refers lithium iron phosphate oxide. Source: ANL (2018b).

Tab. 7.15: Overview of critical material intensity of key battery chemistries. Data source: IEA 2018b, p. 84 after ANL 2018b).

Model	Renault Zoe	Tesla Model 3
Capacity	52 kWh	75 kWh
Technology		NMC 811
Weight	356 kg	479 kg
Lithium	7 kg	6 kg
Manganese	11 kg	6,6 kg
Cobalt	11 kg	7 kg
Nickel	34 kg	56 kg
Copper	85 kg	85 kg

Tab. 7.16: Overview of critical material intensity for two commercial cars. Data sources: FranceTV Info, 2020; Daina et al., 2020; ZSW-BW, 2020.

7.5.5.1 Increase of Raw Materials Demand

Our research has led us to identify possible supply difficulties for materials used for electric mobility, in particular, nickel and lithium (Gallucci, 2021b). The problem is not really the geological volumes available, but rather the ability to extract them at a satisfactory rate to meet the strong growth in demand in the coming years.

This has two main consequences regarding the green batteries pilot project:

- Its pertinence: it will be very important to have an available recycling process to reuse these materials and reduce dependence on external and primary resource extraction.
- The impact of such supply difficulties on the electric vehicle market development: production cannot be as fast as envisioned. The risk is having a battery volume that grows too slowly in the next 20 years, and thus not having a significant volume to process to justify the implementation of an industrial process.

On the other hand, platinum, a critical and costly material for efficient hydrogen production through electrolysis may also be exposed to a supply risk. Current data suggests a need of 0,8g of platinum per 1kw of electrolyser capacity. The long-term target is around 0,1 - 0,2 g Pt/kW (Durville et al., 2015). This risk on supply also underlines the importance of working on the reduction of our needs (especially personal travel by car), to transform our mobility, and not only on its electrification. However, this need is not explicitly targeted in the innovation study but is targeted in the overall territorial strategy.

7.5.5.2 Local Resources

In recent decades, mining materials have been heavily outsourced to less developed countries. But there seems to be an increasing number of voices in favour of exploiting mines in Europe. This appears to be a solution to the supply risks, while operating in better environmental and social conditions. Therefore, we investigated whether there are any interesting geological deposits to exploit in the region, particularly regarding critical materials linked to the pilot projects.

In the Haut-Rhin, the area around Sainte-Marie-aux-Mines was exploited for mining in the last few centuries. Nickel was among many other minerals which were extracted. These mines are no longer in operation and we have no information on the deposits that are still present.

As far as Lithium is concerned, deposits have been found in the geological subsoil of the Upper Rhine Plan. These deposits seem to be exploitable through geothermal in-

stallations and with recent water filtration technologies it seems possible to extract lithium (Potier, 2019; Dugamin et al., 2021). We have already identified two sites with ongoing projects relevant to this topic in the Upper Rhine: Soultz-sous-Forêt (Potier, 2019) and Bruchsal (Eggstein, 2020), with significant volume: around 150 t/y of lithium per site (20 000 electrical car batteries \approx 150 t lithium). This process can be generalised to other geothermal installations in the region. Thus, these projects are worth considering in synergy with the green batteries pilot project.

Lithium has seen a recent sharp increase in price (5-fold by 2021, reaching over \$50/kg by early 2022), and production (Fig. 7.22). It has entered the EU's list of Critical Raw Materials (European Commission, 2020) and European countries are completely dependent on external supplies. Thus, the exploitation of the available deposits in the Upper Rhine seems to have a particularly strategic interest.

7.5.6 Land Use

In this subchapter we present three land use maps around the main pilot project locations: Neuf-Brisach & Breisach am Rhein; Fessenheim; Ottmarsheim & Neuenburg am Rhein (see Figs. 7.23, 7.24 & 7.25). These maps can be used to discuss the best place for the implementation of the pilot.

7.5.6.1 Location of the Hydrogen Plant around Ottmarsheim

Land use data reveal a free space between Borealis and the group Alsachimie-Butachimie-Linde, that are the current hydrogen users of the area. This could be a good and close location for the hydrogen pilot project. Some other areas are also free, but they are farther away from the industrial plants and closer to the residential areas, which is less desirable as regards acceptability concerns.

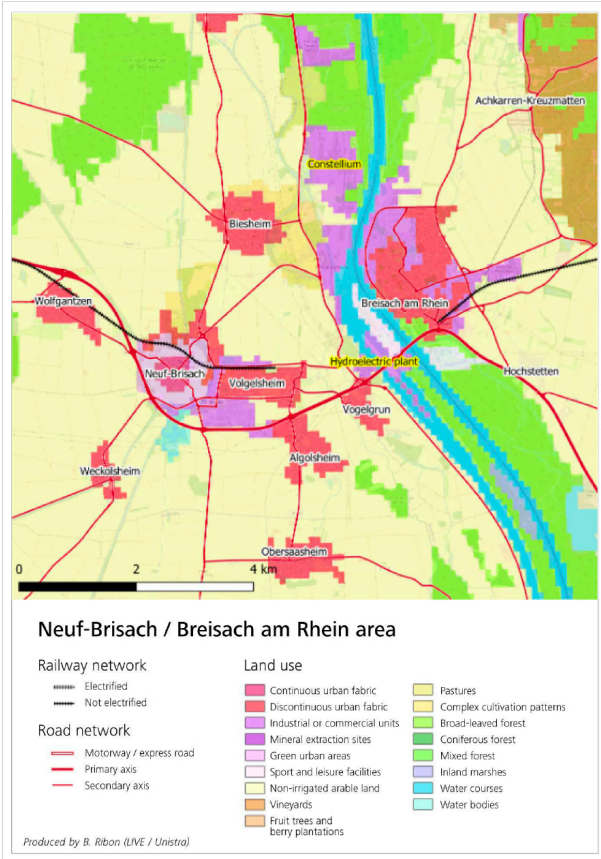


Fig. 7.23: Land use maps: Neuf-Brisach & Breisach am Rhein. Source: Corine Land Cover, OpenStreetMap contributors, Karto-District

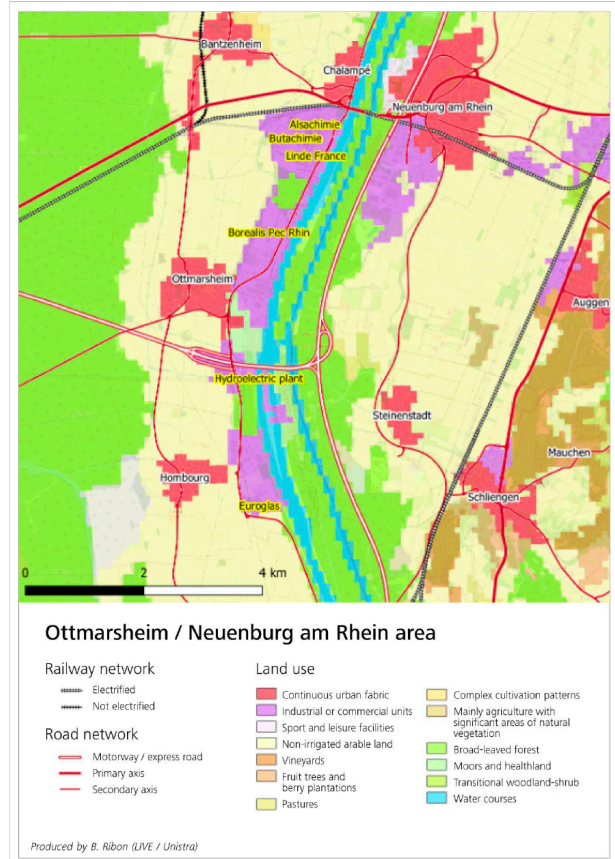


Fig. 7.25: Land use maps: Ottmarsheim & Neuenburg am Rhein. Source: Corine Land Cover, OpenStreetMap contributors, Karto-District

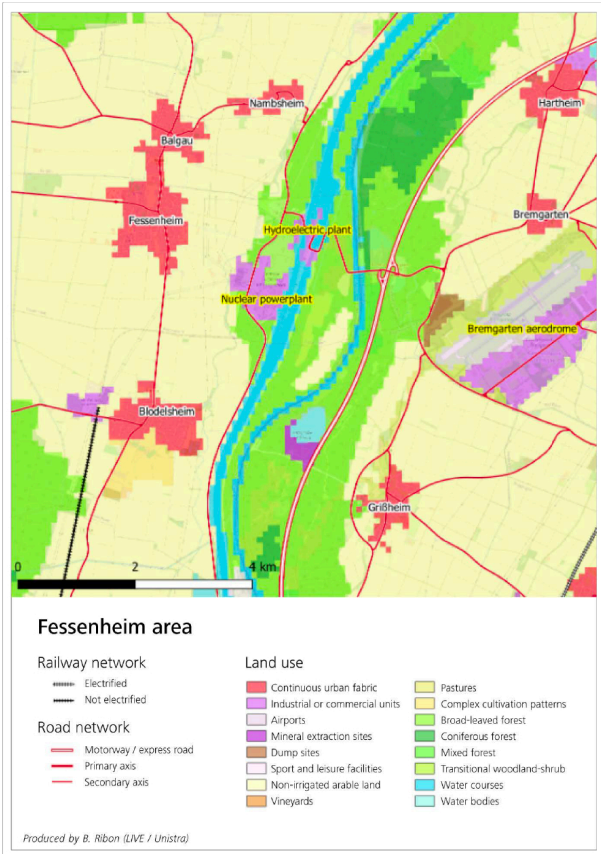


Fig. 7.24: Land use maps: Fessenheim. Source: Corine Land Cover, OpenStreetMap contributors, Karto-District

7.5.7 Conclusions and Recommendations for Territorial Anchoring

Green Batteries Pilots

The current trend, where the electrical vehicle market is growing quickly, will require an efficient end-of-life solution for batteries in a few years (probably five to ten years). The pilot tackles this issue with a large overview: it highlights interesting opportunities for a complete and circular economy of batteries.

The Green Battery project considers a large variety of technologies, with different readiness levels and development timelines. It results in potential synergies but also in interferences or dependencies that should be more clearly highlighted. Some technologies (lowest maturity or with high economy of scale) should consider gathering partners (industrials and politics) beyond the Upper Rhine Region.

Battery recycling techniques are still emerging, subject to technological developments and the pilot project is open to the idea of experimenting with different approaches (manual, mechanical, chemical, biological). The installation site selected - which may consist of several sites - must therefore be designed to evolve and offer the necessary spaces for this experimentation.

The processing capacity of the pilot project (1 tonne of car batteries per day) seems to be adapted to the volume currently available in the territory. In the long-term (15-20 years), we believe that the volumes of electrical car batteries to be recycled will be around 250 tons per day in the Upper-Rhine.

The question of primary resources should also be addressed as it is closely linked to battery issues. The Upper Rhine has deep and significant deposits of Lithium which could be recovered through geothermal energy. Deposits of other minerals, in particular Nickel, also exist in the territory but are no longer exploited. The (re-)exploitation of these deposits deserves to be studied given the importance of these materials in batteries, and the criticality of batteries for electric mobility development.

Hydrogen Pilots

The two proposed locations (NB/BR and OT/NR) and Vieux-Thann are interesting for developing a territorial H₂ ecosystem because of the synergy potential. However, due to a lack of data, it was not possible to evaluate if the pilot project production (3000 tH₂/year) corresponds to the current and future needs.

We note that electricity production capacities are limited, especially in the studied territory. Producing H₂ through

electrolysers may add a significant and almost permanent (for economic profitability) load on the electrical network. There are suitable proposals by the hydrogen competence group to overcome these challenges. Associated PV infrastructures may compensate for some of the load. On the other hand, the territory has significant biomass resources that could be used to produce hydrogen and a better realisation of the technical potentials in the areas needs more intensive discussion.

Smart Grids Pilots

The Smart Grid project mostly relies on energy optimization. "Energy sobriety" should also be underlined for the effectiveness of smart grids.

It is generally quite rare to have detailed data (temporally and spatially) on the energy consumption of a territory. The Smart Grid project should make their data publicly available as scientific contributions to support similar projects elsewhere. This project presents an opportunity to build and disseminate consumption data (with the necessary statistical anonymization) of the considered experimentation field in order to support other projects.

Global Territorial Strategy

The stated objectives of the feasibility study around the Fessenheim region are to reduce greenhouse gas (GHG) emissions and move towards a CO₂ neutral region, make Fessenheim an innovative region, and support employment affected by the closure of the nuclear power plant. It examines the importance of developing technological pilot projects around hydrogen technologies, battery recycling and the development of smart grids.

The examination of the project through the territorial metabolism approach raises questions about the coordination between the pilot projects and the territorial project (Projet de Territoire). While the pilots are interesting in themselves for their contribution to the reduction of GHG emissions, their integration into a coherent territorial policy, including other territories in the vicinity, needs a more thorough examination.

This is particularly noticeable for the production of hydrogen by electrolysis. If technically the project has interests in the two identified favourable sites (Ottmarsheim & Breisach), the interaction between the policies and the economy of the territory is not really clear. Finally, apart from these two sites, there are few other interesting sites for developing hydrogen technologies. Moreover, the production of hydrogen by electrolysis is not particularly innovative and the local production of electricity is currently insufficient to cover these new needs. It would have seemed more appropriate to focus on different (but perhaps less mature) technologies for the production of hy-

drogen (from biogas, thermolysis, thermo-cracking). This does not prevent the development of electrolysis solutions in the short-term in order to quickly start the development of the hydrogen ecosystem, but this development should also be accounted for in a medium and long-term development plan.

Clarifications regarding the territorial development strategy for the studied fields is needed instead of a succession of pilot projects. The rapid deployment of these new sectors seems to require:

- A shared consensus of the public and private stakeholders and players concerned and/or involved in the development of the sectors,
- Significant and explicit public support to limit the additional costs associated with emerging technologies,
- Greater participation by private stakeholders, particularly in sharing their information. It is crucial to have a better understanding of current and potential needs (e.g., for hydrogen) in order to develop appropriate facilities,
- A more explicit coordination of public policies at different territorial levels and with the surrounding territories.

7.6 Legal Framework

The pilot projects are developed in the Franco-German border region. As law is based on the national territories it is important to establish the general principles of German and French law. This comparative description establishes the convergence and differences of both sets of rules to assess both the legal constraints and opportunities for the development of battery production and recycling plants, hydrogen production and smart grids along the Franco-German Rhine. A focus will be made on the possible legal exemptions that can be obtained in French and German law. Possible cross-border pilot projects will be analysed to assess possible legal strategy, especially in the context of the Aachen Treaty.

7.6.1 Battery Production and Recycling

Germany and France both have markedly different legislation regarding battery handling sites. The relevant regulations are listed and explained briefly here.

7.6.1.1 Under German Law

Battery recycling plants are typically plants requiring a permit according to BImSchG – Bundes Immissionsschutzgesetz (Federal Immission Control Act), which, if the

threshold values are exceeded, are subject to a formal immission control procedure according to § 10 BImSchG with public participation. The plants are likely to fall into the catalogue of plants named in the 4th BImSchV according to No. 8.11.1 or No. 8.11.2.

Technically, the following typical operating units are likely to be covered by the permit: storage areas (indoor and outdoor storage for both primary and secondary batteries), a sorting facility, crushing facilities for primary batteries, separation facilities, cooling storage, dismantling facilities for the various battery types, filter facilities for the dismantling and processing facilities (dust and activated carbon filters) as well as workshops, scales and a transformer station.

In this configuration, the plant is not likely to fall under Appendix 1 (especially No. 8) of the UVPG – Gesetz über die Umweltverträglichkeitsprüfung (Environmental Impact Assessment Act), and an UVP – Umweltverträglichkeitsprüfung (EIA - Environmental Impact Assessment) would probably not be required in this respect. However, this would still have to be checked on the basis of the technical specifications.

In this respect, reference can be made to the elements presented above.

7.6.1.2 Under French Law

The production unit requires a series of administrative authorisations which need careful preparation and have a clear cost. Such a plant can be considered as an ICPE (installation classée) according to the Code de l'Environnement. The obligation to declare the activity or to authorize it is clearly described on the ministry website (AIDA1810 2015). It is important to have a precise description of the project to follow the classification procedure.

A single course of action which establishes a unique authorisation procedure (AE 2017, p.4) to the national authorities in charge of the control of the ICPE (L 181-1 du Code de l'Environnement)⁵ has been in place since 2017. A specific dossier must be set up, and the authorities must conduct a public inquiry. The advantage is that a unique control is made on all environmental effects of the projects (on water, Natura 2000 zones, Habitats directive, etc) and other effects. This unique authorisation is a simplification, but a "permis de construire" should also be required from the local authorities. An authorisation to exploit the plant may be requested in a separate procedure before the Préfet.

Both sets of rules require an authorisation to avoid serious threats to the environment. These authorisations are costly and time-consuming; this must be taken into ac-

⁵ For a checklist in the Région Grand Est, see ref. DREAL-GE.

count before any concrete actions. A deeper analysis of the administrative practices is needed to assess the differences of content between the French and German legal approaches.

No specific regulation exists concerning storage of batteries under French Law which constitutes a serious legal risk for the recycling of batteries. One of the questions is the legal treatment of Lithium, which is considered a dangerous product:

- The storage building must be adapted to the danger which varies with the age and condition of the battery;
- As a dangerous product, the transport of Lithium is also regulated through providing adequate information about its handling to the carrier.

7.6.2 Hydrogen Production

Like battery handling which is subject to many restrictions, hydrogen is a similarly regulated commodity, with varying legislation across borders.

7.6.2.1 Under German Law

The legal framework for hydrogen uses in Germany is currently still incomplete (Langstädtler, 2021).

For the production of hydrogen, i.e., the construction and operation of electrolyzers, reformers or separation plants, a formal immission control approval procedure with public participation is regularly required. The legal basis for this procedure is § 10 BImSchG. In principle, this is always applicable if the plant is named in Appendix 1 of the so-called Plant Ordinance (4th BImSchV) and which is marked there with a "G" (cf. Dietlein, in: Landmann/Rohmer, Umweltrecht, 81st EL 2016, § 4 BImSchG Rz. 7f.).

Electrolyzers, reformers or separation plants may be covered by No. 4.1.12 of Appendix 1 of the 4th BImSchV. This covers "installations for the production of substances or groups of substances by chemical, biochemical or biological conversion on an industrial scale [...] for the production of gases such as ammonia, chlorine and hydrogen chloride, fluorine and hydrogen fluoride, carbon oxides, sulphur compounds, nitrogen oxides, hydrogen, sulphur dioxide, phosgene."

The facility must also produce hydrogen on an "industrial scale." The specific threshold for this is, on the one hand, legally unclear (Bringewat, 2017), and, on the other hand, actually unclear (size of the pilot).

Hydrogen storage facilities are also operating sites or other stationary facilities according to § 3 para. 5 no. 1 BImSchG and thus facilities according to the BImSchG.

It must also be examined whether the pilot falls within the scope of § 23b BImSchG and the Major Accidents Ordinance (12th BImSchV), where limits on hydrogen quantity are imposed in number 2.44.

Characteristic for the procedure according to BImSchG is the concentration maximum, according to which in principle all necessary official permits are granted in this procedure (§ 13 BImSchG). Within this framework, the relevant requirements under building planning law (such as Section 35 (1) No. 3 of the German Building Code (BauGB)) must also be taken into account.

The construction of new hydrogen transport networks is not covered by the EnWG – Gesetz über die Elektrizitäts- und Gasversorgung (Electricity and Gas Supply Act). The situation is different for the rededication of existing (underground) gas pipelines. However, the exemption from the UVP pursuant to Section 43 f (2) EnWG does not apply there either. Incidentally, this also applies to the conversion of natural gas storage facilities.

In all cases, it must still be checked whether the threshold values of the UVP are exceeded (§§ 4 ff. UVPG).

7.6.2.2 Under French Law

A Future Major Component of French Energy Mix

The « Loi relative à la transition énergétique pour la croissance verte (2015) » is designed to reduce greenhouse gas. It is based on a national low carbon strategy (2015) wherein greenhouse gas emissions are to be cut by a factor of four by 2050 on the basis of the 1990 levels of emissions and national energy dependence with the objective of 32% of renewable energy on the French energy mix in 2030. After the Paris Agreement (2015), a second low carbon strategy was agreed upon, in 2020, to achieve a reduction of greenhouse gases by a factor of six - and thus abide by this international agreement.

The 2020 strategy establishes the objective to achieve a carbon neutral economy by 2050 based on biomass resources, carbon-free electricity and heat from the environment. Low-carbon hydrogen is more specifically promoted by the "Loi relative à l'énergie et au climat (2019)", with the objective to achieve 20% to 40% of total consumption of industrial hydrogen in 2030. The "ordonnance n° 2021-167 (2021)" and national strategy dedicated to low-carbon hydrogen (2020)⁶ are adopted to develop low-carbon and renewable hydrogen.

⁶ Hydrogen can be produced by water electrolysis from decarbonized electricity or renewables. Such hydrogen is called "decarbonized" as neither its production or usage emits CO₂.

The French General Legal Framework

Hydrogen production, transport, storage and traceability is governed by the new livre VIII of the Code de l'énergie which has been introduced by the "Loi relative à l'énergie et au climat (2019)" and the "ordonnance n° 2021-167 (2021)". Hydrogen is considered as a vector of energy carrying certain dangers from production to storage. Its production, distribution and storage are therefore governed by the ICPE regulation and require a unique environmental authorisation (see supra)⁷.

The «arrêté sur les stations d'hydrogène» describes the legal obligations imposed on the conformity process of hydrogen plants or unit of distribution (stations d'hydrogène), the exploitation of such installations, the respect of security, water management, waste and noise regulations⁸.

Some disposals are specifically dedicated to:

- The injection of hydrogen in the natural gas networks is guaranteed (art. 49 de la loi énergie climat 2019)
- Legal regime of the underground storage of hydrogen. The Mining Code (Code Minier) has been changed to allow the holder of a fuel gas or natural gas storage concession to store hydrogen without any new mining licence.

Definition of Hydrogen

The Code de l'énergie encompasses the definition of the different types of hydrogen: renewable, low-carbon and carbon hydrogen. It defines the rules of traceability and the various subsidies to the production of hydrogen available to develop a French hydrogen capacity.

Hydrogen is considered as a major energy vector for the development of renewable energy resources and low-carbon economy. It is therefore a strong incentive for the development of hydrogen production by the end of 2023 if it is:

- Renewable Hydrogen⁹,
- Low-Carbon Hydrogen¹⁰,
- and Carbon Hydrogen¹¹.

A guarantee of origin is provided for renewable and low-carbon hydrogen mixed with other types of gas in natural gas networks; a market of these guarantees has been created by the Code de l'énergie.

A system of traceability is also provided for non-mixed renewable and low-carbon hydrogen to recognize this type of production on the energy market. Both instruments are managed by a national registry under the supervision of an independent administrative body.

The Région Grand Est has adopted a Hydrogen Strategy for the time span of 2020 to 2030 (Fig. 7.26). Two major objectives are emphasised:

- a low-carbon offer in road and river transports,
- decarbonised industry.

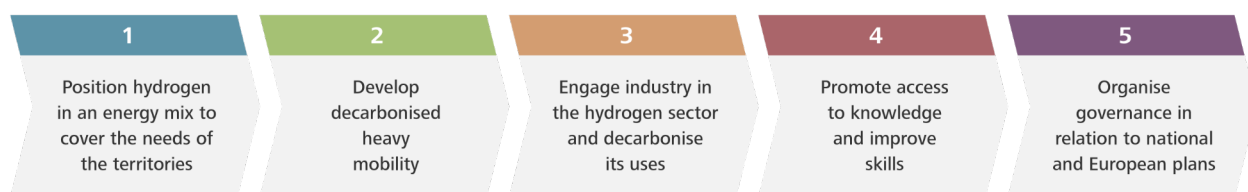


Fig. 7.26: Five axes of the Grand Est hydrogen strategy for 2020 - 2030 (adapted and translated from GEW 2020, p.5)

⁷ Decree No. 2018-900 of October 22, 2018 created section 1416 "Storage or use of hydrogen" in the nomenclature of classified installations (ICPE).

⁸ Order of October 22, 2018 on the general requirements applicable to installations classified for environmental protection subject to declaration under section 1416 (hydrogen gas distribution station) of the nomenclature of classified installations and amending the order of November 26, 2015 on the general requirements applicable to installations using hydrogen gas in an installation classified for environmental protection to supply hydrogen gas carts when the quantity of hydrogen available in the facility falls under the declaration regime for section 4715 and amending the order of August 4, 2014 on the general requirements applicable to installations classified for environmental protection subject to declaration under section 4802.

⁹ Renewable hydrogen: produced from renewable energies whose production process respects a CO₂ threshold per kilogram of hydrogen. These processes are electrolysis using electricity from renewable energy and any other process using renewable energy and "not conflicting with other uses allowing their direct recovery".

¹⁰ Low-carbon hydrogen: subjected to the same CO₂ threshold per kilogram of hydrogen as renewable hydrogen, but produced from non-renewable energy sources, which makes it possible to integrate electrolysis of nuclear origin.

¹¹ Carbon hydrogen: does not meet either of the other two definitions, it includes steam reforming of natural gas or RE production exceeding the CO₂ threshold.

Hydrogen is a key element in the regional energy mix. Industry must provide for the production and transport of hydrogen and the regional policy is aimed at decarbonising the industrial uses. Many objectives correspond to the products and services proposed for the post-Fessenheim project. Many subsidies are available, but Hydrogen must be developed with public subsidies opened for the production of hydrogen by electrolysis of water.

From a legal point of view, the French ecosystem is safe and well-developed. A build-up of French low-carbon hydrogen capacity is considered to be necessary by the French legislator for a low-carbon industry and the development of heavy-mobility using carbon-free hydrogen (as a complementary storage medium for electric batteries). It appears that the legal framework is designed to develop pilot projects and to foster innovative projects. These innovations allow for possible legal derogations.

7.6.2.3 Provisional Legal Derogations for Hydrogen

Article 61 of the “loi relative à l’énergie et au climat” provides for regulatory sandboxes (bac à sable réglementaire). This mechanism allows for experimentation with new technologies or innovative services for energy transition by using specific and provisional legal derogations. The experimentation is strictly delimited for the achievement of the objectives of the Hydrogen strategy and the Code de l’énergie. The Commission de Régulation de l’énergie (CRE) can authorise temporary derogations from the legal conditions of access and use of energy networks. Such an incentive is supposed to boost innovations without waiting for a change of regulatory frameworks.

The conditions of eligibility of sandboxes are the following. The project must:

- Contribute to the achievement of article L100-1 of the Code de l’énergie (energy transition)
- Have an innovative dimension
- Be faced to a clearly identified legislative or regulatory obstacle
- Have a potential future development
- Present a benefit for the society on a long-term basis.

If the project is eligible, a three-month period of in-depth examination by the CRE begins. If the feasibility of the project is confirmed, a specific derogation will be provided by the CRE on a four-year basis. After this period, a report on the derogation will be submitted and a modification of the legislation or the regulation may be decided upon.

It must be underlined that sandboxes already accepted by the CRE meet the following criteria:

- The derogation is possible to solve a specific and well-defined legal obstacle
- The project is clearly an innovative solution or process
- The derogation is targeted to solve the legal obstacle and is provisional

The French Administrative Commission of Energy Regulation has so far accepted considering as legal obstacles the rules governing the injection of gas on an existing public network. It shows the limited possibilities to negotiate sandboxes under French law. The innovative character of hydrogen pilots may allow the identification of other legal obstacles. The legal obstacles only involve a legal derogation from French law. A Franco-German pilot project which requires crossing the border may require a more comprehensive derogation which must be encompassed either in an EU regulation or in the Aachen Treaty. An interesting solution could be to apply French rules as they provide for a more complete legal framework than the German ones.

7.6.3 Smart Grids

With regard to both pilot projects, it must be pointed out that the main aspects in the area of planning and licensing law depend on the specific location of the plant.

In view of the infrastructures that can be used within the framework of the pilot projects, the smart connection of already existing infrastructures such as ports, rail connections, hydropower plants or gas pipelines is recommended rather than developing a new concept.

Concerning the Smart Grids pilot project, the main legal question concerns the legal protection of personal data. This protection is harmonised in the EU by the GDPR (general regulation on the protection of personal data). It means that a common protection of personal data exists in the EU and therefore no major differences exist between France and Germany.

The collection, treatment and storage of personal data must respect the common rights defined by the GDPR (GDPR chapter 3, 2016) and must be respected. It is important to develop the necessary technical tools to guarantee an effective protection of these rights - for example, smart meters (Petric, 2010).

It is also very important to underline that a common governance of data also derives from the GDPR and must be considered to build the economic model of smart grids. Two principles are of major importance: privacy by design (Antignac et al., 2014) and privacy by default. These principles have a direct impact on the economic model of smart meters.

The development of smart grids must take into account the balance with individual freedom such as the freedom of movement of citizens (the balance results from the principle of proportionality). It is important to respect this balance, to avoid the rise of social acceptability concerns of such projects.

7.6.4 Further Aspects

It is interesting to consider the law applicable for the pilots in the innovation region as a bilateral innovative zone along the Rhine. Such a development is promoted by EU energy law and may include the possibility to use the derogation clause existing in the Aachen treaty.

A Favourable European Context to Develop Cross-Border Energy Zone

In terms of European law, it should be noted in particular that a corresponding deviation through the innovation zone must not violate the various prohibitions of discrimination in EU primary and secondary law. Whether the prohibition of state aid has been violated must be examined on a case-by-case basis.

The Green Energy package is promoting a new market design for electricity and a central role for consumers. It consists of 4 directives and 4 regulations.

- The EU Regulation on the Governance of the Energy Union and Climate Action (Regulation 2018/1999): The Governance Regulation sets out how Member States will cooperate with each other and with the European Commission to achieve the targets for renewable energy, energy efficiency and CO₂ emissions. It also provides for monitoring mechanisms to ensure that the targets are met and that all the measures proposed by the Member States are coherent and coordinated. In particular, the regulation sets a 15% interconnection target in relation to installed generation capacity in each Member State by 2030.
- Renewable Energy Directive (Directive 2018/2001): The new text sets a target of 32% for the share of energy produced from renewable sources at EU level by 2030. This new target follows the political agreement that was reached in June 2018 between the Council of the European Union and the European Parliament.
- The Energy Efficiency Directive (Directive 2018/2002): The revised directive sets the target of improving the EU's energy efficiency by at least 32.5% by 2030. It also introduces an obligation to achieve annual energy savings of 0.8% of final energy consumption between 2021 and 2030.

- The Energy Efficiency in Buildings Directive (Directive 2018/844): This directive encourages cost-effective building renovation, introduces a building intelligence indicator, and simplifies inspections of heating and cooling systems.

It is interesting to note that the 2019 directive on new market design comprises specific mechanisms for cross border cooperation to develop decentralised production of electricity based on renewables. Regional management of the supply of electricity is considered as being more effective for consumers and network stability.

Moreover, Article 61-2 of the 2019 directive provides that Regulatory authorities shall cooperate at least at a regional level to:

- Foster the creation of operational arrangements in order to enable an optimal management of the network, promote joint electricity exchanges and the allocation of cross-border capacity, and enable an adequate level of interconnection capacity, including through new interconnection- within the region and between regions- to allow for development of effective competition and improvement of security of supply, without discriminating between suppliers in different Member States
- Coordinate the joint oversight of entities performing functions at regional level
- Coordinate, in cooperation with other involved authorities, the joint oversight of national, regional and European resource adequacy assessments
- Coordinate the development of all network codes and guidelines for the relevant transmission system operators and other market actors
- Coordinate the development of the rules governing the management of congestion
- Give regulatory authorities the right to enter into cooperative arrangements with each other to foster regulatory cooperation (EEA 2020, MOT 2019).

(Berrod et al., 2016, HBF 2017, HBF 2018, PASSAGE 2018, Pescia et al., Carlin et al., 2018)

7.6.5 Legal Opportunities to Benefit from Derogations to Build an Innovation Zone

With regard to the question of the extent to which a type of special "legal innovation zone" in the area of tax law or urban development planning, plant approval law or the regulatory regime under which plants operate, would be permissible for such a cross-border project, reference must be made to the constitutional framework of the Member States as an imperative legal basis.

7.6.5.1 German Approach

Insofar as such an innovation zone is to take place based on the existing legal framework, this would be inadmissible due to the constitutional principle of the lawfulness of administration (Article 20 (3) of the Basic Law) in the absence of corresponding exemption provisions already standardised by law. Insofar as such an innovation zone is to be established on the basis of new statutory exemption regulations yet to be created, it should be noted that a general - i.e., overlapping various specialised laws - general clause-like exemption regulation would be inadmissible under constitutional law due to the expected infringement of the rule of law principle of Article 20 (3) GG in. Individual case and special law-related exemption regulations would also have to be subordinate to the constitutional prohibition of discrimination under Article 3 (1) of the Basic Law - provided they satisfy the principle of definiteness. Unequal treatment of this innovation zone would have to be justified by factual reasons that are appropriate to the differentiation objective and the extent of the unequal treatment. This would have to be examined in depth on a case-by-case basis (Missling et al., 2016).

It should be noted that there are various activities by the German government to establish real-world laboratories and corresponding legal exemptions (Reallabore, 2021). This includes initiatives to provide a legal basis for such exemptions, which are also part of the coalition agreement of the new federal government (Koalitionsvertrag, 2021).

There has also been work on the practical design and implementation of such regulatory experiments (Bauknecht et al., 2021) that can be the basis for implementing such experiments in the Upper Rhine region.

7.6.5.2 Under French Law

The principle of equality of article 1 of the Constitution prohibits any differentiation unless it is justified by a general interest or if it is necessary to treat different situations. Two such situations can be used as an illustration:

- Differentiation of competences between regions gave birth for example to the Collectivité Européenne d'Alsace, by application of the law of 2 August 2019, which is competent for example on the management of national roads and local highways (which is normally the competence of the French state). The importance of the road transport along the Rhine explains the need for a differentiation
- Differentiation is possible to define specific modality of exercise of certain competences such as the obligation to guarantee in each town at least 20% social housing (loi du 13 Décembre 2000, dite « SRU »)

The current debates on the loi 4D show the limited possibility of differentiation that can be foreseen with this law. The project presented by the government encompasses a specific provision to develop differentiated approaches. A report of the Assemblée Nationale proposes an interpretation of this new approach of differentiation (Jacquier-Laforge 2021) which means that differentiation is possible and may even be maintained after an experimental period of time. It nevertheless appears that derogation is possible only in relation with the competences or rules of functioning of competences belonging to the "Département Français". It is not the case for fiscal competences for example and therefore the ambit of possible differentiation is limited.

7.6.6 Possibilities Opened by the Aachen Treaty (2019)

Insofar as the Treaty of Aachen, in particular the so-called experimentation clause of Art. 13 Par. 2, is cited as a conceivable lever, it must be pointed out that the possibilities mentioned there only exist "with due regard for the respective constitutional rules of the two states and within the framework of the law of the European Union". In this respect, this does not change the framework described above.

Article 13 does allow for a derogation if no other instruments can solve the specific obstacle to cross-border projects. Such an obstacle must be defined before any demand for derogation. In many cases a correct application of national rules or a solution provided by EU law or Council of Europe convention is sufficient to solve the obstacle. It means that the derogation clause is used only if the application of EU or national law is not sufficient to solve a specific obstacle. It is not possible to deduce from the Aachen treaty a general derogation from national laws. This interpretation is in line with the sandboxes approach existing in France (see above).

There exists a limit to the possibility of application of a derogation, to avoid any normative dumping: the derogation must comply with the preservation of strict rules of environmental and social protection. The derogation clause of the Aachen Treaty also implies a political will of both French and German states.

This also needs to be seen in the context of developments on the EU level, such as:

- EU Council Conclusions on Regulatory Sandboxes and Experimentation Clauses 13026/20: Regulatory sandboxes can provide the opportunity for advancing regulation through proactive regulatory learning, enabling regulators to gain better regulatory knowledge and find the best means to regulate in-

novations based on real-world evidence, especially at a very early stage, which can be particularly important in the face of high uncertainty and disruptive challenges, as well as when preparing new policies.

- Horizon Europe: Mission Approach: Missions are by definition 'experimental'. They provide a learning lab for policy experimentation

7.7 Summary

Innovative ideas are always prone to technological challenges and although cross-border scientific expertise in the Upper Rhine region is an asset for tackling those challenges, the main challenge left to overcome is the territorial one. The territory is very complex, and its complexity is increased by its transnational nature. Therefore, a framework of multiple dimensions in which the overall project has to be adopted is required.

Green technologies are generally supported by the public. Hydrogen appeared to be the most acceptable technology, followed by Green Batteries and then Smart Grids. The two most promising identified levers with positive impact appear to be the image conveyed (affect) and the associated benefits as both are positively correlated to the level of acceptability. Therefore, we recommend careful communication. The more positive the image (positive affect), the more likely it is for the project to be considered acceptable.

In addition, a territory is a living entity whose metabolism can be studied in order to analyse the mobilised resources and question the territorial anchoring of a project. The installation of manufacturing plants for hydrogen or batteries should be quite feasible due to a large number of equipped business development sites in the territory and land availability. Some of them are located along the Rhine, which is an undeniable logistical asset. Moreover, some sites host industries that are already linked to hydrogen or batteries, which allows the development of positive industrial ecology conditions. Building on the existing industrial fabric and creating synergies through sectoral coupling is a win-win strategy that, in the long run, will not only provide alternative and decarbonized energy sources but also de-fossilize the production methods of existing industries.

However, the transformation of Fessenheim into a sustainable and innovative region raises legal issues linked to the existence of two, French and German, legislative systems across the border from each other. There are innovative solutions within these legislations but, they need to be identified and applied in order to develop this project. Cross-border cooperation could be the key to developing an attractive legal framework that would favour the concretization of the project. If legal obstacles were to be

identified for the envisioned cross-border coupling of green technologies or the implementation of specific facilities etc., cross-border cooperation could act as a legal tool that enables territories facing the same problems to experiment with and develop solutions together. Existing French legal options for innovative projects could be applied and possibly extended to Germany and vice-versa or new-for-both solutions could be implemented.

In conclusion, it is also worth underlining the marked interest of national, regional and especially local authorities that can support the development of the pilot projects. The Upper Rhine regional assets such as high population density, high standard of living, leading universities and research centers, industries of interest, and support from local and national authorities provide the perfect conditions and strengthen the feasibility of the project.

7.8 Recommendations

Social Acceptability

First, regarding the psychological determinants, one of the objectives of the study was to conduct a comparative analysis between the general French population and the local population in Fessenheim and its surroundings. The idea was to highlight potential specificities (if any) for the local population which is directly affected by the project and already transitioning. Several local associations were contacted, most of them very active in the territory and willing to contribute to the decision-making process. However, none of them followed up. The questionnaire was also sent to local groups via social networks. It also proved unsuccessful. No local data was collected to date. Our final sample was therefore made up only of respondents from the general French population. The next interesting step would be to conduct the same study within the general German population for comparison.

From a more general perspective, we propose using a transdisciplinary approach in planning and implementing the three proposed innovative technologies at the specific sites chosen. Based on other experiences in planning and implementation of contested infrastructures (eg. deep geothermal energy or nuclear energy facilities), the participation of the various regional players is a very important factor for the integration of different perspectives and knowledge as well as the adjustment of the different planning and implementation processes to suit the perceptions and needs of local residents (Ejderyan et al., 2020; Krütli et al., 2012; Mbah & Krohn, 2021; Mbah & Kuppler, 2021). A transdisciplinary approach is suitable to foster collaborative project design and knowledge production (Lam et al., 2021; Lutz & Bergmann, 2018; Newig et al., 2019; Pohl et al., 2017). Here, the real-world laboratory format might be a promising format - maybe in an

adopted way - to accompany and design the planning and implementation process (Bergmann et al., 2021; Parodi et al., 2018; Schöpke et al., 2018; Wanner et al., 2018). In this format, selected stakeholders, called practitioners, are directly involved in developing a solution, here a collaborative planning and implementation process design for the three proposed innovative technologies.

In this respect, the first step will be to identify the relevant local stakeholders which should be selected and integrated in the collaborative process. As far as the cross-border region is concerned, practitioners from both sides need to be integrated, as not only do legal and institutional frameworks differ in the two national contexts, but cultural and historical experiences do so as well. (Enserink et al., 2007; Llewellyn et al., 2017; Knaps, 2021; Mbah & Kuppler, 2021). The second step is to arrive at a common understanding of the problem framing and the aim of the project. Basis for the identification of the most relevant issues which should be addressed in the planning and implementation process is a context analysis which might be either collaboratively developed with the practitioners involved or beforehand, based on the findings of the feasibility study. Accordingly, specific issues will be identified for further analysis. The aim could be the development of technological and socio-technical criteria which need to be met in implementation scenarios. Criteria and scenarios need to be jointly developed. It is expected that the scenarios will cover recommendations for communication and participation in the planning and decision-making process as well as specific recommendations for technical adjustment.

Environmental Impact

Many steps in the life cycle of a product could be integrated into a life cycle analysis. We recommend including either the transportation, redistribution and/or end uses for both Green Batteries and Hydrogen projects in the next step. As for hydrogen production, in order to reduce its environmental impacts, it seems necessary to focus on the energy source that powers the electrolyser during its production phase, rather than specifically on the choice of a type of electrolysis as the electrical source impacts the environmental aspects over the entire life cycle. We recommend comparing different sources of renewable and/or carbon-free energy (hydraulic, wind, nuclear (French side), etc.) including safety and economical aspects.

Territorial Metabolism

For accompanying the pilots in their developments on the territory, we recommend the following sets of tasks:

- First Set: (i) Analysis of additional critical materials in relation to the projects: Cobalt / Manganese / Platinum (similar to the Nickel and Lithium analysis already provided); (ii) Analysis of the climatic conditions of the territory and the consequences on the intermittency of energy production; (iii) Consolidation of the energy analysis and the inventory of production means on the territory (electricity, biogas, biofuels)
- Second set: (i) Issues and opportunities in sharing data within the industrial ecosystem; (ii) Study of the necessary logistics on the territory for battery recovering
- Third set: (i) Prospective study of the battery market (all types of batteries and in all stages: 1st-life, 2nd-life and end-of-life); (ii) Green battery/ hydrogen projects benchmarking in other close territories; (iii) State of the technology of the different reuse and recycling techniques; (iv) State of the technology of the different hydrogen production means and applications, interference and synergies on the electrical network (power-to-gas-to-power, high-power electrolysers); (v) Evaluation of the current and future hydrogen market in the territory, evolution of hydrogen capacities, production means and usage; (vi) Political and territorial coordination for innovation

Legal Framework

From the point of view of competence group 4, the development of integrated and cross-border integrated spatial development concepts in border areas, especially in the Trinational Metropolitan Region Upper Rhine, poses numerous highly interesting research questions in the legal and administrative fields, both in the area of basic research and in the area of application-oriented research.

The complementarity extends both externally to other, for example, technical or economic research areas, as well as internally between the regional players, who are jointly in the situation to research the legal-administrative area in energy and environmental law from the International and European legal to the municipal level, both basic and application-oriented cross-border.

The technical pilot projects can be used to identify legal and regulatory issues and barriers and develop new legal and regulatory approaches that are needed to upscale the technical solutions in a sustainable way.

The development and operation of regulatory innovation zones, in cooperation with the technical pilots, can be further used to test such new legal and regulatory approaches.

7.9 Contacts

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8. Conclusion

The feasibility study has demonstrated that the Innovation Region Fessenheim is endowed with a number of assets (see Chapter 2) that could help it develop into a European cross border regional innovation system (CBRIS). In order to effectively use the proposed ideas for its development, the selected pilots need to be further elaborated on to concretize and clarify the ideas proposed and to construct for each one discrete implementation plans. For more detailed planning of the pilots or a selection of pilots, a consortium needs to be established with communal and European level stakeholders and industrial partners that possess scientific and administrative knowhow as well as legal competences. The selected pilots from different fields can demonstrate how the transformation towards sustainability is linked with the different technological innovation fields. For example, the generation of renewables is on one hand linked with the capacity of producing green hydrogen through electricity and, on the other, with smart grid systems to achieve optimal and timely electricity distribution with minimal losses. Equally important is the link between the stabilisation of the electricity grid and battery storage capacity as well as the link between battery storage and the need to recycle batteries for protecting the environment/climate and lessening the dependency on imported raw materials. Keeping the interdependencies in mind, a holistic approach of the interlinked pilots and their implementation in a region is essential to learning about the overall transformation process towards sustainability.

Choosing the Upper Rhine region with its energy intensive industry clusters around Basel, Chalampé and Karlsruhe is an optimal way to demonstrate the benefits of regional cross-border innovation hubs towards more sustainability. Furthermore, it provides the chance to demonstrate, after the decommissioning of a nuclear plant (Fessenheim), how a cross-border region can be transformed into a prospering future-oriented innovation region within a relatively short time frame by joining the resources of both sides of the border. Above all, decreasing dependence on fossil and nuclear energy sources is symbolic for an area that previously hosted a nuclear plant on its grounds and especially for its citizens who lived in the vicinity of this plant and feel strongly about the issue.

Besides, the benefits of cross-border hubs are many: overcoming administrative and legal barriers, providing regional expertise that transcends national borders, and accelerating knowledge transfer between companies, societies and science organisations. Cross-border hubs increase cross-border flexibility for employees and multiply the resources for joint investments. Likewise, cross-border hubs advance intercultural understanding, join political visions, and strengthen by joint activities Europe's position in the world. A number of economists have even proved that value addition in cross-border hubs is significantly large (EC study on the quantification of cross border effects, EC, 2017).

The Feasibility Study Innovation Region Fessenheim outlines preliminary possible pilot projects developed based on the identified regional strengths. The most feasible option is to implement these pilots in the same region as they can not only provide best practice examples of how an innovative transformation towards sustainability is put into action but can also demonstrate how nations on both sides of a border can benefit from cross-border joint activities. As a matter of fact, feedback provided by industry partners during several workshops confirmed that the proposed pilot projects are in line with their future plans. In the workshops, the partners also highlighted the pressure for a timely implementation of such pilots in order to gain the know-how and to scale-up for industrial facilities.

According to a statement by Frans Timmermans, Executive Vice-President for the European Green Deal (2022): "The green transition will free us from our dependence on energy- and other resource imports. The circular economy more specifically will allow us to reduce our demand for primary resources, and use a lot less energy for our production and consumption". All the proposed pilots in the feasibility study comply with this statement and help to achieve this demand. Moreover, all pilots can be further investigated by the reader and are described in the form of a pilot sheet in the folder attached to this document. The pilot sheets will provide a basis for the concretization of the pilot ideas. Finally, the pilots' implementation requires large investments which must be mainly secured as start-up funds and through public funds from a European to a regional level that can be used for refining and detailing the plans. Mixed public-private partnerships could provide the investments required for the pilot infrastructures.

For the acceleration of the above mentioned process, the next steps need to be implemented in a timely manner as per statements of industry members:

1. Formation of a management group to coordinate and administer activities (including public relations) for the innovation region with the goal of pilot implementation
2. Concretization of the pilot ideas by detailing the implementation requests, like the compilation of interested consortia members from science and industry, administrations, and society stakeholders for each pilot
3. Elaboration of the pilot's details and execution plans
4. Formation of a steering group for all decision levels related to politics, industry, and societal as well as regional stakeholders
5. Formation of a territorial framework group to accompany the implementation planning related to environmental, societal, and regulative matters
6. Implementation of investor approach activities and an investment plan for companies and public and private investors
7. Determination of a start date for the pilots along with the public relation activities

In conclusion, it is imperative that the abovementioned steps be executed within a tight time frame. As mentioned previously, feedback from the workshops with industry members has indicated that time is of the essence for taking the lead in the innovation field and creating an impact in this decade.

Bibliography

Executive Summary

European Commission (2017). Quantification of the effects of legal and administrative border obstacles in land border regions. Final report. Retrieved from: https://ec.europa.eu/regional_policy/sources/docoffic/2014/boosting_growth/quantif_effect_borders_obstacles.pdf

Chapter 1

Hamman, P. (Ed.). (2021). Cross-Border Renewable Energy Transitions: Lessons from Europe's Upper Rhine Region (1st ed.). Routledge.
<https://doi.org/10.4324/9781003199977>

Projet de Territoire (2019). Projet de territoire de Fessenheim / Raumprojekt Fessenheim; available online in French and German:
<http://www.haut-rhin.gouv.fr/Politiques-publiques/Avenir-du-territoire-de-Fessenheim/Zukunft-des-Raumes-Fessenheim-Avenir-du-territoire-de-Fessenheim>

Roland Berger GmbH (2020). Potenziale der Wasserstoff- und Brennstoffzellen-Industrie in Baden-Württemberg. Study commissioned by the State of Baden-Württemberg. Retrieved from:
https://www.rolandberger.com/publications/publication-_pdf/roland_berger_wasserstoff_und_brennstoffzellenindustrie.pdf

Treaty of Aachen (2019). The Treaty of Aachen on Franco-German Cooperation and Integration from 22.01.2019. Retrieved from:
<https://www.diplomatie.gouv.fr/de/frankreichs-beziehungen-zu-deutschland-osterreich-und-der-schweiz/bilaterale-beziehungen-zu-deutschland/der-deutsch-franzosische-kooperationsvertrag-von-aachen/>

Chapter 2

Conseil départemental du Haut-Rhin & Conseil départemental du Bas-Rhin (2019). Elsässische Strategie zur grenzüberschreitenden Kooperation im trinationalen Oberrheingebiet. Retrieved from:

https://www.haut-rhin.fr/sites/haut_rhin/files/SO_Strat%C3%A9gie_DE.Light__0.pdf

Deutsch-französisch-schweizerische Oberrheinkonferenz (2014). Verbindung / Trait d'union. L'actualité des transports dans le Rhin supérieur / Aktuelle Themen der Verkehrspolitik am Oberrhein. Retrieved from: https://www.regbas.ch/de/assets/File/downloads/trait_d_union_verbindung.pdf

EDF (2019). Jahresbericht zur Information der Öffentlichkeit über die kerntechnischen Anlagen in FESSENHEIM. Paris. Retrieved from: https://www.edf.fr/sites/default/files/contrib/groupe-edf/producteur-industriel/carte-des-implantations/centrale-fessenheim/surete-et-environnement/rapportannuel/2020_de_rapport_fessenheim.pdf

EUCOR (2022). Eucor – The European Campus. Accessed on 10.02.22 from: <https://www.eucor-uni.org/de/startseite/>

European Commission (2017). Quantification of the effects of legal and administrative border obstacles in land border regions. Final report. Available online: https://ec.europa.eu/regional_policy/sources/docoffic/2014/boosting_growth/quantif_effect_borders_obstacles.pdf

European Commission (2020). Communication from the Commission- A new industrial strategy for Europe. COM/2020/102 final. Available online: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0102>

Unterzeichnung der Strategie (2030) der Trinationale Metropolregion am Oberrhein (TMO) accessed on 03.03.2022 from <https://www.rmtmo.eu/de/>

Préfecture de la Région Grand Est. 2019. LIAISON FERROVIAIRE ENTRE COLMAR ET FRIBOURG: Étude de mobilité multimodale. Strasbourg: Préfecture de la Région Grand Est

Projet de Territoire (2019). Projet de territoire de Fessenheim / Raumprojekt Fessenheim; available online in French and German: <http://www.haut-rhin.gouv.fr/Politiques-publiques/Avenir-du-territoire-de-Fessenheim/Zukunft-des-Raumes-Fessenheim-Avenir-du-territoire-de-Fessenheim>

Regierungspräsidium Freiburg, n.d., Upper Rhine. Accessed on 20.12.2021 from : <https://rp.baden-wuerttemberg.de/rpf/sgz-en/upper-rhine/>

Treaty of Aachen (2019). The Treaty of Aachen on Franco-German Cooperation and Integration. Retrieved from: <https://www.diplomatie.gouv.fr/de/frankreichs-beziehungen-zu-deutschland-osterreich-und-der-schweiz/bilaterale-beziehungen-zu-deutschland/der-deutsch-franzosische-kooperationsvertrag-von-aachen/>

Zuoza, A., and Pilinkienė, V. (2021). Energy Efficiency and Carbon Emission Impact on Competitiveness in the European Energy Intensive Industries. *Energies* 2021, 14(15)

Chapter 3

Axpo (2018): Water's Power, Retrieved from: <https://www.axpo.com/ro/en/magazine/renewable-energy/the-power-of-the-river.html>

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

Barbier (2002): Barbier E. (2002), Geothermal Energy Technology and Current Status: An Overview, *Renewable and Sustainable Energy Reviews*, 6 (1): 3–65, doi: [https://doi.org/10.1016/S1364-0321\(02\)00002-3](https://doi.org/10.1016/S1364-0321(02)00002-3).

Cousse, J. (2021): Still in love with solar energy? Installation size, affect, and the social acceptance of renewable energy technologies, *Renewable and Sustainable Energy Reviews*, Vol. 145, July 2021.

Dèzes et al. (2004): Dèzes P., Schmid S. M. & Ziegler P. A. (2004), Evolution of the European Cenozoic Rift System: Interaction of the Alpine and Pyrenean Orogens with Their Foreland Lithosphere, *Tectonophysics*, 389 (1): 1–33, doi: <https://doi.org/10.1016/j.tecto.2004.06.011>.

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

EEA et al. (2019): European Environment Agency, Lechner Knowledge Center (Lechner Tudásközpont) & Umweltbundesamt (2019), Updated CLC Illustrated Nomenclature Guidelines, Retrieved from: https://land.copernicus.eu/user-corner/technical-library/corine-land-cover-nomenclature_guidelines/docs/pdf/CLC2018_Nomenclature_illustrated_guide_20190510.pdf

EnBW (n.d.): Hydropower, Retrieved from: <https://www.enbw.com/renewable-energy/wasserkraft/>

European Parliament (n.d.): European Parliament, Fact Sheets on the European Union (Webpage) Retrieved from: <https://www.europarl.europa.eu/factsheets/en/sheet/70/renewable-energy>

Eurostat (n.d.): Retrieved from: <https://ec.europa.eu/eurostat/data/database>

Fraunhofer ISE (Ed.) (2020): Fraunhofer Institute for Solar Energy Systems ISE (2020), Agrivoltaics: Opportunities for Agriculture and the Energy Transition, Retrieved from: <https://www.ise.fraunhofer.de/en/publications/studies/agrivoltaics-opportunities-for-agriculture-and-the-energy-transition.html>

GeORG-project team (2013): GeORG-project team (2013), Geopotenziale des tieferen Untergrundes im Oberrheingraben. Fachlich-technischer Abschlussbericht des Interreg-Projekts GeORG, Teil 2: Geologische Ergebnisse und Nutzungsmöglichkeiten, Freiburg, Retrieved from: https://www.geopotenziale.org/home/index_html.

Grau et al. (2017): 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* 2017, 9: 1169, doi: <https://doi.org/10.3390/su9071169>

Harlé et al. (2019): Harlé P., Kushnir A. R.L., Aichholzer C., Heap M. J., Hehn R., Maurer V., Baud P., Richard A., Genter A. & Düringer P. (2019), Heat Flow Density Estimates in the Upper Rhine Graben Using Laboratory Measurements of Thermal Conductivity on Sedimentary Rocks, *Geothermal Energy*, 7 (1): art. 38, doi: <https://doi.org/10.1186/s40517-019-0154-3>

Huld (2017): 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, doi: <https://doi.org/10.1016/j.solener.2016.12.014>.

ICPR (2015): International Commission for the Protection of the Rhine (December 2015), Internationally Coordinated Management Plan 2015 for the International River Basin District of the Rhine Retrieved from: https://www.iksr.org/fileadmin/user_upload/Dokumente_en/Broschures/CMP_2015_-_en.pdf

Jäger et al. (2016): 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, doi: <https://doi.org/10.1016/j.renene.2016.05.013>.

Jung & Schindler (2017): 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, doi: <https://doi.org/10.1016/j.enconman.2017.07.033>.

Jung & Schindler (2018): Jung C. & Schindler D. (2018), 3D Statistical Mapping of Germany's Wind Resource Using WSWS, *Energy Conversion and Management*, 159: 96–108, doi: <https://doi.org/10.1016/j.enconman.2017.12.095>.

- Jung & Schindler (2019): Jung C. & Schindler D. (2019), 'The Role of Air Density in Wind Energy Assessment – A Case Study from Germany', *Energy*, 171: 385–392, doi: <https://doi.org/10.1016/j.energy.2019.01.041>.
- Jung (2016): Jung C. (2016), High Spatial Resolution Simulation of Annual Wind Energy Yield Using Near-Surface Wind Speed Time Series, *Energies* 2016, 9: 344, doi:10.3390/en9050344
- Mainzer et al. (2014): 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, doi: <https://doi.org/10.1016/j.solener.2014.04.015>.
- Manwell et al. (2009): Manwell J. F., McGowan J. G. & Rogers A. L. (2009), *Wind Energy Explained: Theory, Design and Application*, Chichester, John Wiley & Sons, doi: <https://doi.org/10.1002/9781119994367>.
- McKenna et al. (2021): McKenna R., Pfenninger S., Heinrichs H., Schmidt J., Staffell I., Bauer C., Gruber K., Hahmann A.N., Jansen M., Klingler M., Landwehr N., Larsen X. G., Lilliestam J., Pickering B., Robinus M., Tröndle T., Turkovska O., Wehrle S., Weinand J. M. & Wohland J., (October 2021), High-resolution large-scale onshore wind energy assessments: A review of potential definitions, methodologies and future research needs, *Renewable Energy*, (Vol. 182, p. 659-684), doi: <https://doi.org/10.1016/j.renene.2021.10.027>
- Miocic (2021): Report 2.2.1. Hydrogen storage in the Upper Rhine Graben. Potential analysis. Available online: Retrieved from: <https://www.res-tmo.com/en/> [to be uploaded]
- Najjar et al., 2022: Najjar Z., Gavrilut I. & Miocic J. (2022) Report 2.1.1.: Representation of RES Potentials, RES-TMO, Interreg V., Retrieved from: https://www.res-tmo.com/fileadmin/PDFs/Outputs/RES-TMO_Deliverable_2.1.1.pdf
- Rudi et al. (2017): Rudi A., Fröhling M. & Schultmann F. (April 2017), *Waste Biomass Valor*, 8: 2313–2327, Biomass Value Chain Design: A Case Study of the Upper Rhine Region, doi: <https://doi.org/10.1007/s12649-016-9820-x>
- Sanjuan et al. (2006): Sanjuan B. , Pinault J. L., Rose P., Gérard A., Brach M. , Braibant G., Crouzet C., Foucher J. C. , Gautier A. & Touzelet S. (2006), Tracer Testing of the Geothermal Heat Exchanger at Soultz-Sous-Forêts (France) between 2000 and 2005, *Geothermics*, 35 (5): 622–653, doi: <https://doi.org/10.1016/j.geothermics.2006.09.007>.
- Sarbu & Sebarchievici (2014): Sarbu, I. & Sebarchievici, C. (2014), General Review of Ground-Source Heat Pump Systems for Heating and Cooling of Buildings. *Energy and Buildings*, 70, 441-454, doi: <https://doi.org/10.1016/j.enbuild.2013.11.068>*
- Schindele et al. (2020): Schindele S., Trommsdorff M., Schlaak A., Obergfell T., Bopp G., Reise C., Braun C., Weselek A., Bauerle A., Högy P., Goetzberger A., & Weber E. (2020), Implementation of Agrophotovoltaics: Techno-Economic Analysis of the Price-Performance Ratio and its Policy Implications, *Applied Energy*, 265, doi: <https://doi.org/10.1016/j.apenergy.2020.114737>
- Schumacher et al. (Eds.) (2017): Schumacher K., Fichtner W. & Schultmann F., *Innovations for Sustainable Biomass Utilization in the Upper Rhine Region*, KIT Scientific Publishing, doi: <https://doi.org/10.5445/KSP/1000048433>
- TRION-Climate e.V. (2019): Trinationaler Klima- und Energiebericht, (2019) Treibhausemissionen, Energieverbrauch, Erneuerbare: Umsetzung der Klima- und Energieziele am Oberrhein, Kehl, Retrieved from: https://trionclimate.net/fileadmin/Aktivitaeten/Trion_Studien/Energiebericht/Trinationaler_Klima-_und_Energiebericht_TRION_Nov._2019_final.pdf.
- TRION-climate, GeoRhena (2020): Best-Practice-Karte: Erzeugungsanlagen für erneuerbare Energie am Oberrhein. TRION-climate e.V./ GeoRhena. Available online: <https://trion-climate.net/energieanlagen>
- Vrînceanu, A., Grigorescu, I., Dumitrașcu, M., Mocanu, I., Dumitrică, C., Micu, D., Kucsicsa, G., Mitrică, B. (2019): Impacts of Photovoltaic Farms on the Environment in the Romanian Plain. *Energies* 12(13).
- 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, Retrieved from: <https://publikationen.bibliothek.kit.edu/250099732>
- Wüstenhagen, R., Wolsink, M., Bürer, M. J. (2007): Social acceptance of renewable energy innovation: An introduction to the concept. *Energy Policy* 35 ,2007, pp. 2683–2691

Chapter 4

Dühnen, S., Betz, J., Kolek, M., Schmuck, R., Winter, M., Placke, T. (2020). Toward Green Battery Cells: Perspective on Materials and Technologies. *Small Methods*, 4, 2000039.

European Commission (2019). A European Green Deal. Striving to be the first climate-neutral continent. Retrieved from: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

European Commission (2020). A new Circular Economy Action Plan For a cleaner and more competitive Europe. COM/2020/98 final. Retrieved from: https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0017.02/DOC_1&format=PDF

Gattiglio, F. (2017): Battery energy storage in the EU, ees conference, Munich 2017.

International Renewable Energy Agency (2019). Innovation landscape brief: Behind-the-meter batteries. Abu Dhabi. Retrieved from: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_BTM_Batteries_2019.pdf

Chapter 5

FeLis (2021). Najjar Z., Saroos M., & Koch B. Estimating the Hydrogen Demand in the Industry of the Upper Rhine Region (France & Switzerland) as part of the Feasibility Study for the Fessenheim Innovation Region (unpublished Internal Report)

Fraunhofer ISE (2021). Wasserstofftechnologien am Südlichen Oberrhein H2-SO. Retrieved from: <https://www.ise.fraunhofer.de/de/forschungsprojekte/h2-so.html>

Fraunhofer ISE (2016). Photovoltaics and Photosynthesis – Pilot Plant at Lake Constance Combines Electricity and Crop Production. <https://www.ise.fraunhofer.de/en/press-media/press-releases/2016/photovoltaics-and-photosynthesis-pilot-plant-at-lake-constance-combines-electricity-and-crop-production.html>

Galkina, E., Vasyutina, O. (2018). IOP Conf. Ser.: Mater. Sci. Eng. (365) 022047. doi:10.1088/1757-899X/365/2/022047

Hydrogen Europe (2020): Clean Hydrogen Monitor 2021. Retrieved from: <https://hydrogeneurope.eu/reports/>

H2-SO (2021). H2-SO - Wasserstofftechnologien am Südlichen Oberrhein. Retrieved from: http://innoeff.aufwind-solutions.de/de-de/aktuelles/news/news/h2-so-wasserstofftechnologien_am_suedlichen_oberrhein-2020-06-09-105

IEA (2019). "The Future of Hydrogen. Seizing today's opportunities. Report prepared by the IEA for the G20, Japan". Retrieved from: <https://www.iea.org/reports/the-future-of-hydrogen>

Jade L., Wei-Hsin, C., Tsang, D.C.W., You, S. (2020). A critical review on the principles, applications, and challenges of waste-to-hydrogen technologies. *Renewable and Sustainable Energy Reviews*. (134) 110365. 1-14

Keyou (2021). Press Release. Retrieved from: https://www.keyou.de/wp-content/uploads/2021/06/20210525_PM-KEYOU_EU-Contract-Signed_english_LM_MB19.pdf

Maack, J. (2018). Regional availability of lignocellulose as primary resource for Baden-Württemberg: A contribution to assessing the capacity, positioning and sustainable resource supply for future biomass-based conversion facilities. Doctoral thesis. University of Freiburg.

Observatoire de l'hydrogène Vig'hy (2021): Observatoire de l'hydrogène Vig'hy, Retrieved from: <https://vighy.france-hydrogene.org/>

RES-TMO report (2022). Representation of RES Potentials, RES-TMO, Interreg V., Retrieved from: https://www.res-tmo.com/fileadmin/PDFs/Outputs/RES-TMO_Deliverable_2.1.1.pdf

Ruf, Y., Baum, M., Zorn, T., Menzel, A., Rehberger, J. (2020). Fuel Cells Hydrogen Trucks- Heavy Duty's High Performance Green Solution. Retrieved from: https://www.rolandberger.com/publications/publication_pdf/roland_berger_fuel_cells_hydrogen_trucks.pdf

TRION-Climate e.V. (2019). Treibhausmissionen, Energieverbrauch, Erneuerbare: Umsetzung der Klima- und Energieziele am Oberrhein, Kehl. Retrieved from: https://trionclimate.net/fileadmin/Aktivitaeten/Trion_Studien/Energiebericht/Trinationaler_Klima-_und_Energiebericht_TRION_Nov_2019_final.pdf

Wasserstofftechnologien am Südlichen Oberrhein H2-SO, n.d. Forschungsprojekte H2-SO. Retrieved from: <https://www.ise.fraunhofer.de/de/forschungsprojekte/h2-so.html>

Chapter 6

Act "Digitisation of the Energy Transition". (2016). Available online: The digitisation of the energy transition

Butt, O.M., Zulqarnain, M., Butt, M.T. (2021). Recent advancement in smart grid technology: Future prospects in the electrical power network. *Ain Shams Engineering Journal*, (12) 1. 687-695.

ENTSO-E Transmission System Map. Retrieved from: <https://www.entsoe.eu/data/map/>

Ministerium für Umwelt, Klima- und Energiewirtschaft Baden-Württemberg (2022). Projekt: Smart East. Accessed on 18.01.2022 from: <https://um.baden-wuerttemberg.de/de/umwelt-natur/nachhaltigkeit/nachhaltige-digitalisierung/projekte/smart-east/>

RES-TMO report (2022). Representation of RES Potentials, RES-TMO, Interreg V., Retrieved from: https://www.res-tmo.com/fileadmin/PDFs/Outputs/RES-TMO_Deliverable_2.1.1.pdf

Seven2one Informationssysteme GmbH (2022). Smart East Karlsruhe- Das Projekt. Accessed on 18.01.2022 from <https://smart-east-ka.de/startseite/>

Chapter 7

* Acceptation sociale — Géoconfluences (no date). Available at: <http://geoconfluences.ens-lyon.fr/glossaire/acceptation-sociale>

AE 2017: L'autorisation environnementale, Ministère de la Transition écologique. URL: <https://www.ecologie.gouv.fr/sites/default/files/L'autorisation%20environnementale.pdf>

AIDA1810 2015: La réglementation de la prévention des risques et de la protection de l'environnement. URL: https://aida.ineris.fr/consultation_document/10521

* Aitken, M. (2010). Why we still don't understand the social aspects of wind power: A critique of key assumptions within the literature, *Energy Policy*, 38(4), pp. 1834–1841. doi: 10.1016/j.enpol.2009.11.060

* Akrich, M. (1993) 'Les objets techniques et leurs utilisateurs de la conception à l'action', in *Les Objets dans l'action*. Paris: Editions l'EHESS, pp. 35–57.

* Akrich, M. (1994) 'Les utilisateurs, acteurs de l'innovation', *Éducation permanente*, (134), pp. 78–89.

* Akrich, M. (no date) 'Comment décrire les objets techniques?', p. 17.

* Akrich, M., Callon, M. and Latour, B. (no date) 'A quoi tient le succès des innovations? 1: L'art de l'intéressement; 2: Le choix des porte-parole', p. 43.

* Amand, R., Ducoulombier, P. and Millet, F. (2021) 'Transition énergétique et hydrogène: le Living Lab ou l'ébauche d'une recherche participative', *VertigO - la revue électronique en sciences de l'environnement*, (Hors-série 34). doi: 10.4000/vertigo.29989.

Antignac et al., 2014: Antignac T., Le Métayer D. (2014) Privacy by Design: From Technologies to Architectures. In:

Preneel B., Ikonomidou D. (eds) Privacy Technologies and Policy. APF 2014. Lecture Notes in Computer Science, vol 8450. Springer, Cham. https://doi.org/10.1007/978-3-319-06749-0_1

* Baba, S. and Mailhot, C. (2016). De la controverse à l'acceptabilité sociale: le rôle constructif du conflit, *VertigO - la revue électronique en sciences de l'environnement*, (Volume 16 Numéro 1). doi: 10.4000/vertigo.16917

* Baba, S. and Raufflet, E. (2015). L'acceptabilité sociale: une notion en consolidation, *Management international / International Management / Gestión Internacional*, 19(3), pp. 98–114. doi: 10.7202/1043005ar

* Barki, H. and Hartwick, J. (1994). Measuring User Participation, User Involvement, and User Attitude, *MIS Quarterly*, 18(1), pp. 59–82. doi: 10.2307/249610

Batel et al., 2013: Batel, S., Devine-Wright, P., & Tangeland, T. (2013). Social acceptance of low carbon energy and associated infrastructures: A critical discussion. *Energy Policy*, 58, 1–5. <https://doi.org/10.1016/j.enpol.2013.03.018>

* Batellier, P. (2016). Acceptabilité sociale des grands projets à fort impact socio-environnemental au Québec: définitions et postulats, *VertigO - la revue électronique en sciences de l'environnement*, (Volume 16 Numéro 1). doi: 10.4000/vertigo.16920

Bauknecht et al., 2021: Bauknecht, D., Heyen, D. A., Gailhofer, P., Bizer, K., Feser, D., Führ, M., Winkler-Portmann, S., Bischoff, T. S., Proeger, T. (2021). How to design and evaluate a Regulatory Experiment? A Guide for Public Administrations. Freiburg, Berlin, Göttingen, Darmstadt.

* Bell, D. et al. (2013). Re-visiting the "social gap": public opinion and relations of power in the local politics of wind energy, *Environmental Politics*, 22(1), pp. 115–135. doi: 10.1080/09644016.2013.755793.

* Bell, D., Gray, T. and Haggett, C. (2005). The "Social Gap" in Wind Farm Siting Decisions: Explanations and Policy Responses, *Environmental Politics*, 14(4), pp. 460–477. doi: 10.1080/09644010500175833

* Bergeron, K. M. et al. (2015). Mesurer l'acceptabilité sociale d'un projet minier: essai de modélisation du risque social en contexte québécois, *VertigO*, (Volume 15 Numéro 3). doi: 10.4000/vertigo.16737

Bergmann et al., 2021: Bergmann, M.; Schöpke, N.; Marg, O.; Stelzer, F.; Lang, D. J.; Bossert, M. et al. (2021): Transdisciplinary sustainability research in real-world labs:

success factors and methods for change. In: *Sustainability Science* 16, S. 541–564.

Berrod et al., 2016: Berrod, F.; Navé, L. (2016): *Fostering Investment in Cross-Border Energy Infrastructure in Europe*, Center for European Policy Studies.

* Bigerna, S., Bollino, C. A. and Micheli, S. (2016) 'Socio-economic acceptability for smart grid development – a comprehensive review', *Journal of Cleaner Production*, 131, pp. 399–409. doi: 10.1016/j.jclepro.2016.05.010.

Bostrom et al., 2018: Bostrom, A, Böhm, G., & O'Connor, R.E. (2018). *Communicating risk: Principles and Challenges*. In M. Raue, E. Lerner, & B. Streicher (Eds.), *Psychological Perspectives on Risk and Risk Analysis: Theory, Models, and Applications* (pp. 251-278). Springer.

* Bourdin, S. (2020) 'Le NIMBY ne suffit plus! Étude de l'acceptabilité sociale des projets de méthanisation', *L'Espace Politique*. Revue en ligne de géographie politique et de géopolitique, (38). doi: 10.4000/espacepolitique.6619.

* Bourdin, S., Jeanne, P. and Raulin, F. (2020) '« La méthanisation, oui, mais pas chez moi! » Une analyse du discours des acteurs dans la presse quotidienne régionale', *Natures Sciences Sociétés*, Vol. 28(2), pp. 145–158

Bringewat, 2017: Bringewat, J. (2017). *Rechtsfragen bei der Zulassung von Elektrolyseurprojekten*, jurOP. URL: <http://www.jurop.org/oeffbaurecht/aktuelle-rechtsfragen-bei-der-zulassung-von-elektrolyseurprojekten/>

* Callon, M., Lhomme, R. and Fleury, J. (1999) 'Pour une sociologie de la traduction en innovation', *Recherche & Formation*, 31(1), pp. 113–126. doi: 10.3406/refor.1999.1574.

* Callon, M. (2006) 'Sociologie de l'acteur réseau', in *Sociologie de la traduction*, Textes fondateurs. Paris: Presse des Mines (Sciences Sociales), pp. 267–276.

Carlin et al., 2018: Carlin, E. Magdalinski (Jacques Delors Institute), I. Cochran (I4CE), 2018.

Caron et al., 2005: Caron, P. and Cheylan, J.-P. (2005). *Donner sens à l'information géographique pour accompagner les projets de territoire : cartes et représentations spatiales comme supports d'itinéraires croisés*, *Géocarrefour*, 80 (vol. 80/2), pp.111–122. doi: 10.4000/geocarrefour.1031.

* Cherqui, A. and Bombenger, P.-H. (2019) 'La transition énergétique à travers le prisme des espaces de vie : les dynamiques de recadrages cognitifs autour de projets

éoliens en Suisse occidentale', *Lien social et Politiques*, (82), pp. 96–117. doi:10.7202/1061878ar

* Chesbrough, H., Vanhaverbeke, W. and West, J. (2008) *Open Innovation: Researching A New Paradigm*.

Clouet, 2000: Clouet, Y. (2000). *Le zonage à dire d'acteurs. Méthode et perspectives*, Bois et Forêts des Tropiques. Available at: <https://agritrop.cirad.fr/476685/>.

* Cohendet, P., Héraud, J.-A. and Llerena, P. (2010) 'La dynamique de l'innovation: une interprétation de l'approche de Michel Callon en termes de communautés de connaissance', in *Débordements: Mélanges offerts à Michel Callon*. Paris: Presses des Mines (Sciences Sociales).

* Communication, D. G. (no date) *Acceptabilité sociale*, Publicationnaire. Available at: <http://publicationnaire.humanum.fr/notice/acceptabilite-sociale/>

CSF Mines et métallurgie, 2020: *Projet « Développement d'une filière intégrée de recyclage des batteries lithium », Développement d'une filière intégrée de recyclage des batteries lithium*, fév. 2020, 70p

Dailland et al., 2021: Dailland, A., Quaranta, G. (2021). *Évaluation des impacts environnementaux liés à la production d'hydrogène*. Université de Strasbourg. URL: <https://seafire.unistra.fr/f/a95654a7c9c14af990e6/>

Daina et al., 2020: Daina Paulikas, Steven Katona, Erika Ilves, Saleem H. Ali, 2020, *Life cycle climate change impacts of producing battery metals from land ores versus deep-sea polymetallic nodules*, *Journal of Cleaner Production*, Volume 275. DOI: 10.1016/j.jclepro.2020.123822

Directive 2018/2001: Directive (UE) 2018/2001 du Parlement européen et du Conseil du 11 décembre 2018 relative à la promotion de l'utilisation de l'énergie produite à partir de sources renouvelables, <https://eur-lex.europa.eu/legal-content/FR/TXT/?qid=1588261014023&uri=CELEX:32018L2001>

Directive 2018/2002: Directive (UE) 2018/2002 du Parlement européen et du Conseil du 11 décembre 2018 modifiant la directive 2012/27/UE relative à l'efficacité énergétique : <https://eur-lex.europa.eu/legal-content/FR/TXT/HTML/?uri=CELEX:32018L2002>

Directive 2018/844: Directive (UE) 2018/844 du Parlement européen et du Conseil du 30 mai 2018 modifiant la directive 2010/31/UE sur la performance énergétique des bâtiments et la directive 2012/27/UE relative à l'efficacité énergétique : <https://eur-lex.europa.eu/legal-content/FR/TXT/?uri=CELEX%3A32018L0844>

- DREAL-GE: DREAL Grand Est. L'autorisation unique et environnementale. URL: <http://www.grand-est.developpement-durable.gouv.fr/l-autorisation-unique-et-environnementale-r138.html>
- Dugamin et al., 2021: Dugamin, E.J.M., Richard, A., Cathelineau, M. et al. (2021). Groundwater in sedimentary basins as potential lithium resource: a global prospective study. *Sci Rep* 11, 21091. DOI: 10.1038/s41598-021-99912-7
- * Dupuis, N. (2019). L'acceptabilité sociale de l'hydrogène et son processus de co-construction, un enjeu pour la transition énergétique dans les territoires. Doctoral thesis, Université du Littoral Côte d'Opale. HAL: <https://tel.archives-ouvertes.fr/tel-02491400>
- Durville et al., 2015: Durville, J.L., Gazeau, J.C., Nataf, J.M. Cueugnet, J., Legait, B., 2015. Filière hydrogène-énergie - Rapport à des membres du gouvernement. URL: https://www.economie.gouv.fr/files/files/directions_services/cge/filiere-hydrogene-energie.pdf
- EEA 2020: European Environment Agency. Cross-border cooperation on renewable energy (2020). URL: <https://www.eea.europa.eu/themes/energy/renewable-energy/cross-border-cooperation-on-renewable-energy>
- Eggstein, 2020: Eggstein, F. (2020). Sustainability in focus: Lithium for batteries from the Upper Rhine Plain, EnBW. URL: <https://www.enbw.com/company/press/research-project-lithium-production-in-geothermal-energy-plant.html>
- Ejderyan et al., 2020: Ejderyan, O.; Ruef, F.; Stauffacher, M. (2020): Entanglement of Top-Down and Bottom-Up: Socio-technical Innovation Pathways of Geothermal Energy in Switzerland. In: *The Journal of Environment & Development* 29 (1), S. 99–122.
- Emmerich et al., 2020: Emmerich, P., Hülemeier, A.-G., Jendryczko, D., Baumann, M. J., Weil, M., & Baur, D. (2020). Public acceptance of emerging energy technologies in context of the German energy transition. *Energy Policy*, 142, 111516. <https://doi.org/10.1016/j.enpol.2020.111516>
- Enserink et al., 2007: Enserink, B., Patel, M., Kranz, N., & Maestu, J. (2007). Cultural factors as co-determinants of participation in river basin management. *Ecology and Society*, 12(2). <https://doi.org/10.5751/ES-02096-120224>.
- * Ern -Heintz, V. (2019) 'Croiser les regards pour renouveler l'analyse du risque', *Revue d'Allemagne et des pays de langue allemande*, 50(2), p. doi: <https://doi.org/10.4000/allemande.940>.
- * Ern -Heintz, V. (2020a) 'La sant  environnementale: un autre regard sur le risque ou comment le savoir profane s'invite dans l' valuation du risque', *Amnis*, 19, p. [En ligne]. doi: <https://doi.org/10.4000/amnis.5237>.
- * Ern -Heintz, V. (2020b) 'Le savoir profane pour r v ler une in galit  environnementale', *Environ Risque Sante*, 19, pp. 281–285. doi:10.1684/ers/2020/1454
- European Commission 2020, Study on the EU's list of Critical Raw Materials – Final Report. URL: <https://ec.europa.eu/docsroom/documents/42883/attachments/1/translations/en/renditions/native>
- FaHyence, 2017: FaHyence, Premi re station hydrog ne en France connect e   un  lectrolyseur. URL: <https://mcphy.com/fr/realisations/mobilite-hydrogene/fahyence/?cn-reloaded=1>
- Fan et al., 2021: Fan, Xiaoping, Chunlei Tan, Yu Li, Zhiqiang Chen, Yahao Li, Youguo Huang, Qichang Pan, Fenghua Zheng, Hongqiang Wang, et Qingyu Li. 2021. « A Green, Efficient, Closed-Loop Direct Regeneration Technology for Reconstructing of the LiNi0.5Co0.2Mn0.3O2 Cathode Material from Spent Lithium-Ion Batteries ». *Journal of Hazardous Materials* 410 (mai): 124610. <https://doi.org/10.1016/j.jhazmat.2020.124610>.
- * Firey, W. (1962) 'Man, Mind, and Land: A Theory of Resource Use', *Social Forces*, 40(3), p. 279. doi:<https://doi.org/10.2307/2573649>.
- * Fortin, M. M.-J., Fournis, M. Y. and Beaudry, M. R. (no date) 'Acceptabilit  sociale,  nergies et territoires: de quelques exigences fortes pour l'action publique', p. 29.
- * Fournis, Y. and Fortin, M.-J. (2015) 'Une d finition territoriale de l'acceptabilit  sociale: pi ges et d fis conceptuels', *Vertigo*, (Volume 15 Num ro 3). doi: 10.4000/vertigo.16682
- FranceTV Info, 2020: Lithium, cobalt, mangan se, cuivre, aluminium: produire une voiture  lectrique est-il vraiment  cologique ? URL: https://www.francetvinfo.fr/meteo/climat/video-lithium-cobalt-manganese-cuivre-aluminium-produire-une-voiture-electrique-est-il-vraiment-ecologique_4183381.html
- Frietsch-Sch neberg, 2019: Frietsch M., Sch neberg M., 2019. So startet die Elektrifizierung der Breisacher Bahn in Gottenheim. *Badische Zeitung*. URL: <https://www.badische-zeitung.de/so-startet-die-elektrifizierung-der-breisacher-bahn-in-gottenheim>
- Gallucci, M. (2021a): Using AI to Find Essential Battery Materials: As battery demand soars, researchers are turning to artificial intelligence for more effective and sustain-

able methods. *IEEE Spectrum*. URL: <https://spectrum.ieee.org/ai-tools-find-essential-battery-materials>

Gallucci, 2021b: Gallucci, M. (2021). EVs Will Drive A Lithium Supply Crunch, *IEEE Spectrum*. URL: <https://spectrum.ieee.org/evs-to-drive-a-lithium-supply-crunch>

GDPR chapter 3, 2016: General Data Protection Regulation, Chapter 3 (2016). URL: <https://gdpr-info.eu/chapter-3/>

* Gendron, C. (2014) 'Penser l'acceptabilité sociale: au-delà de l'intérêt, les valeurs', *Communiquer. Revue de communication sociale et publique*, (11), pp. 117–129. doi: 10.4000/communiquer.584.

* Gendron, C., Yates, S. and Motulsky, B. (2016) 'L'acceptabilité sociale, les décideurs publics et l'environnement. Légitimité et défis du pouvoir exécutif', *VertigO - la revue électronique en sciences de l'environnement*, (Volume 16 Numéro 1). doi: 10.4000/vertigo.17123

GEW 2020: Grand Est Website (2020). Une stratégie hydrogène pour le Grand Est 2020 - 2030. URL: <https://www.grandest.fr/wp-content/uploads/2020/12/3222-hydrogene-strategie-v8-1.pdf>

* Gheorghiu, M. (2021) 'La « configuration en tiers-lieu », une mise en scène du changement social', *VertigO - la revue électronique en sciences de l'environnement*, (Hors-série 34). doi: 10.4000/vertigo.30064

* Grunwald, A. (2005) 'Zur Rolle von Akzeptanz und Akzeptabilität von Technik bei der Bewältigung von Technikkonflikten', *TATuP - Zeitschrift für Technikfolgenabschätzung in Theorie und Praxis*, 14(3), pp. 54–60. doi: 10.14512/tatup.14.3.54

Harper et al, 2019: Harper, G.; Sommerville, R.; Kendrick, E.; Driscoll, L.; Slater, P.; Stolkin, R.; Walton, A.; Christensen, P.; Heidrich, O.; Lambert, S.; Abbott, A.; Ryder, K.; Gaines, L.; Anderson, P. Recycling lithium-ion batteries from electric vehicles. *Nature* 2019, 575 (7781), 75–86.

HBF 2017: Enhancing Regional Renewables Cooperation in the EU, Experiences and policy recommendations from a study tour to the North Sea region, Heinrich Böll Foundation, 2017

HBF 2018: The European Energy Atlas: Facts and figures about renewables in Europe, Heinrich Böll Foundation, 2018

Hoffrage & Garcia-Retamero, 2018: Hoffrage, U, & Garcia-Retamero R. (2018). Improving understanding of health-relevant numerical information. In M. Raue, E. Ler-

mer, & B. Streicher (Eds.), *Psychological Perspectives on Risk and Risk Analysis: Theory, Models, and Applications* (pp. 279-298). Springer.

Huijts et al., 2012: Huijts, N. M. A., Molin, E. J. E., & Steg, L. (2012). Psychological factors influencing sustainable energy technology acceptance: A review-based comprehensive framework. *Renewable and Sustainable Energy Reviews*, 16, 525-531. <https://doi.org/10.1016/j.rser.2011.08.018>

Huijts et al., 2014: Huijts, N. M. A., Molin, E. J. E., & van Wee, B. (2014). Hydrogen fuel station acceptance: A structural equation model based on the technology acceptance framework. *Journal of Environmental Psychology*, 38, 153-166. <https://doi.org/10.1016/j.jenvp.2014.01.008>

* IFP Energies Nouvelles (2018) 'Tout savoir sur l'hydrogène', IFPEN. URL: <https://www.ifpenergiesnouvelles.fr/enjeux-et-prospective/decryptages/energies-renouvelables/tout-savoir-lhydrogene>

IEA 2018a: International Energy Agency (2018): World Energy Outlook 2018. Organisation for Economic Co-operation and Development (OECD).

IEA 2018b: International Energy Agency (2018). Global EV Outlook – Towards cross-modal electrification. URL: https://iea.blob.core.windows.net/assets/387e4191-acab-4665-9742-073499e3fa9d/Global_EV_Outlook_2018.pdf

* Jammes, L. (2021) 'Regards croisés sur les feuilles de route hydrogène de trois pays: le Canada, le Japon et la France. Quels enseignements?', *VertigO - la revue électronique en sciences de l'environnement*, (Hors-série 34). doi: 10.4000/vertigo.30135

Jacquier-Laforge 2021: Rapport Jacquier-Laforge, Questel, Sage n° 4721 de l'Assemblée nationale du 25 novembre 2021

* Joyce, S. and Thomson, I. (2000) 'Earning a Social Licence to Operate: Social Acceptability and Resource Development in Latin America', *The Canadian Mining and Metallurgical Bulletin*, 93(1037)

Kautzmann et al., 2021: Kautzmann, P., Quaranta, G., Rose, B. (2021). Etude des impacts environnementaux liés aux procédés de recyclage des batteries lithium-ion. Université de Strasbourg. URL: <https://seafile.unistra.fr/f/cce5e0351e774b1c9a0e/>.

* Kline, S. J. and Rosenberg, N. (2009) 'An Overview of Innovation', in Rosenberg, N., *Studies on Science and the*

Innovation Process. WORLD SCIENTIFIC, pp. 173–203. doi: 10.1142/9789814273596_0009

Knaps, 2021: Knaps, F. (2021): Raumbezogene Identität als Faktor für eine nachhaltige Raumplanung. Dissertation. Hannover: Gottfried Wilhelm Leibniz Universität Hannover.

Koalitionsvertrag, 2021: Die Bundesregierung website. Koalitionsvertrag zwischen SPD, Bündnis 90/Die Grünen und FDP (2021). URL: <https://www.bundesregierung.de/breg-de/service/gesetzesvorhaben/koalitionsvertrag-2021-1990800>

* Kortsch, T., Hildebrand, J. and Schweizer-Ries, P. (2015) 'Acceptance of biomass plants – Results of a longitudinal study in the bioenergy-region Altmark', *Renewable Energy*, 83, pp. 690–697. doi:10.1016/j.renene.2015.04.059

Krütli et al., 2012: Krütli, P.; Stauffacher, M.; Pedolin, D.; Moser, C.; Scholz, R. W. (2012): The Process Matters, Fairness in Repository Siting for Nuclear Waste. In: *Social Justice Research* 25 (1), S. 79–101.

* Lacey, J. and Lamont, J. (2014) 'Using social contract to inform social licence to operate: an application in the Australian coal seam gas industry', *Journal of Cleaner Production*, 84, pp. 831–839. doi:10.1016/j.jclepro.2013.11.047

Lam et al., 2021: Lam, D.; Freund, M. E.; Kny, J.; Marg, O.; Mbah, M.; Theiler, L.; Bergmann, M.; Brohmann, B.; Lang, D.; Schäfer, M. (2021): Transdisciplinary research: towards an integrative perspective. In: *Gaia* (30/4), S. 243–249.

Langstädtler, 2021: Langstädtler, S. (2021). Brauchen wir ein Wasserstoffinfrastrukturgesetz?, *ZUR* 2021, 203.

* Lapostolle, D. (2021) 'Analyser les trajectoires territoriales de transition énergétique', *VertigO - la revue électronique en sciences de l'environnement*, (Hors-série 34). doi: 10.4000/vertigo.30105

* Lefeez, S. (2021) 'La préparation de l'armée américaine à la transition énergétique', *VertigO - la revue électronique en sciences de l'environnement*, (Hors-série 34). doi: 10.4000/vertigo.30189.

* Lemarchand, F. (2021) 'La place de l'imaginaire technique dans la transformation de systèmes sociotechniques. Contribution aux transitions studies', *VertigO - la revue électronique en sciences de l'environnement*, (Hors-série 34). doi: 10.4000/vertigo.30224

* Lerner, J. and Tirole, J. (2002) 'Some Simple Economics of Open Source', *The Journal of Industrial Economics*, 50(2), pp. 197–234. doi:10.1111/1467-6451.00174

Li et al., 2017: Li, Xuelei, Jin Zhang, Dawei Song, Jishun Song, et Lianqi Zhang. 2017. « Direct Regeneration of Recycled Cathode Material Mixture from Scrapped LiFePO₄ Batteries ». *Journal of Power Sources* 345 (mars): 78–84. <https://doi.org/10.1016/j.jpowsour.2017.01.118>.

* Lianos, M. (2021) 'Le leadership partagé, Capillarité et relayage dans la transition énergétique', *VertigO - la revue électronique en sciences de l'environnement*, (Hors-série 34). doi: 10.4000/vertigo.30385

Llewellyn et al., 2017: Llewellyn, D. H.; Rohse, M.; Day, R.; Fyfe, H. (2017): Evolving Energy Landscapes in the South Wales Valleys. Exploring Community Perception and Participation. In: *Energy Policy* 108, S. 818–828.

* Loeser, F. (no date) 'Modélisation probabiliste de l'influence des émotions sur l'acceptabilité des innovations', p. 369

Lutz & Bergmann, 2018: Lutz, L. M.; Bergmann, M. (2019): Transdisziplinarität. Forschungsansatz für die Energiewende. In: Holstenkamp, L.; Radtke, J. (Hg.) (2018): *Handbuch Energiewende und Partizipation*. Wiesbaden: Springer VS; S. 43–56.

* Maestripiéri, N. and Saqalli, M. (2016) 'Assessing health risk using regional mappings based on local perceptions: A comparative study of three different hazards', *Human and Ecological Risk Assessment: An International Journal*, 22(3), pp. 721–735. doi:10.1080/10807039.2015.1105099.

Mbah & Krohn, 2021: Mbah, M.; Krohn, J. (2021): Die Bedeutung von Kommunikation und Beteiligung in der Planung und Umsetzung von Geothermievorhaben – eine Fallstudie zu Staufen (D) und St. Gallen (Ch). *Öko-Institut Working Paper 1/2021*; Freiburg, Darmstadt: Öko-Institut e.V. URL: <https://www.oeko.de/fileadmin/oekodoc/WP-Geothermievorhaben.pdf>.

Mbah & Kuppler, 2021: Mbah, M.; Kuppler, S. (2021): Raumsensible Long-term Governance zur Bewältigung komplexer Langzeitaufgaben. Anforderungen im deutschen Entsorgungskontext. In: Brohmann, B. et al. (Hg): *Robuste Langzeit-Governance bei der Endlagersuche. Soziotechnische Herausforderungen im Umgang mit hochradioaktiven Abfällen*. Bielefeld: Transcript; S. 413–446.

* McKinsey Energy Insights Global Energy Perspective. Reference-Case-Summary.pdf (2019). URL: <https://www.mckinsey.com/~media/McKinsey/Industries/Oil%20an>

d%20Gas/Our%20Insights/Global%20Energy%20Perspective%202019/McKinsey-Energy-Insights-Global-Energy-Perspective-2019_Reference-Case-Summary.ashx.

* Midler, C. et al. (2010) 'L'innovation de rupture à l'épreuve du feu', *L'Expansion Management Review*, N° 139(4), pp. 28–37

* Millet, F. and Ducoulombier, P. (2021) 'Living Lab de recherche et médiation scientifique: une tentative d'innovation populaire', *Vertigo - la revue électronique en sciences de l'environnement*, (Hors-série 34). doi:10.4000/vertigo.30249

Missling et al., 2016: Missling/Lange/Michaels/Weise: Möglichkeiten und Grenzen einer probeweisen Weiterentwicklung spezifischer Regelungen des Energiewirtschaftsrechts im Wege sog. „Regulatorischer Innovationszonen“, *EnWZ* 2016, 203.

* Moore, G. A. (1991) *Crossing the chasm Marketing and selling disruptive products to mainstream customers*, 3rd edition - Poche, HarperBusiness. New York.

Mossali et al., 2020: Mossali, Elena, Nicoletta Picone, Luca Gentilini, Olga Rodríguez, Juan Manuel Pérez, et Marcello Colledani. 2020. « Lithium-Ion Batteries towards Circular Economy: A Literature Review of Opportunities and Issues of Recycling Treatments ». *Journal of Environmental Management* 264 (juin): 110500. <https://doi.org/10.1016/j.jenvman.2020.110500>.

MOT 2019: The MOT guides n°10 (2019). The energy transition and cross-border cooperation. URL: http://www.espaces-transfrontaliers.org/fileadmin/user_upload/documents/Documents_MOT/Cahiers/MOT_Guide_10_EN.pdf

MTE-DES, Statista : Ministère de la Transition Ecologique - Données et études statistiques [<https://www.statistiques.developpement-durable.gouv.fr/donnees-sur-les-immatriculations-des-vehicules>], Statista [<https://de.statista.com/statistik/daten/studie/204620/umfrage/neuzulassungen-von-personenkraftwagen-in-baden-wuerttemberg/>]

MUKEBW, 2019. Erneuerbare Energien in Baden-Württemberg 2019, Ministerium für Umwelt, Klima und Energiewirtschaft Baden-Württemberg. URL: https://um.baden-wuerttemberg.de/fileadmin/redaktion/m-um/intern/Dateien/Dokumente/2_Presse_und_Service/Publikationen/Energie/Erneuerbare-Energien-2019-bf.pdf

* Naudon, F. (2021) 'La transition énergétique normande mise à l'épreuve par des profanes-néophytes', *Vertigo - la revue électronique en sciences de l'environnement*, (Hors-

série 34). doi: 10.4000/vertigo.30275

Neef et al, 2021: Neef, C., Schmaltz, T., Thielmann, A. (2021). Recycling von Lithium-Ionen-Batterien: Chancen und Herausforderungen für den Maschinen- und Anlagenbau. Kurzstudie im Auftrag der IMPULS-Stiftung, Fraunhofer-Institut für System- und Innovationsforschung. URL: https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cct/2021/VDMA_Kurzstudie_Batterierecycling.pdf

Newig et al., 2019: Newig, J.; Jahn, S.; Lang, D. J.; Kahle, J.; Bergmann, M. (2019): Linking modes of research to their scientific and societal outcomes. Evidence from 81 sustainability-oriented research projects. In: *Environmental Science and Policy* (101), S. 147–155.

* 'p-fiche_enr_acceptabilite.pdf' (no date). URL: http://www.adeus.org/productions/plateforme-dappui-a-la-transition-energetique-des-territoires/files/p-fiche_enr_acceptabilite.pdf?fbclid=IwAR0vBj8jxtOS-j0ukusTQVH6EMtme401vMewF1mt3g5Ae7nJMadcTIRnPG0.

* Park, C.-K., Kim, H.-J. and Kim, Y.-S. (2014) 'A study of factors enhancing smart grid consumer engagement', *Energy Policy*, 72, pp. 211–218. doi: 10.1016/j.enpol.2014.03.017

Parodi et al., 2018: Parodi, O.; Waitz, C.; Bachinger, M.; Kuhn, R.; Meyer-Soylu, S.; Alcántara, S.; Rhodius, R. (2018): Insights into and Recommendations from Three Real-World Laboratories. An Experience-Based Comparison. In: *Gaia* (27/S1), S. 52–59.

PASSAGE 2018: Carbon emissions study in the European Straits of the PASSAGE project, Final Report, 2018

* Pécaud, D. (2021) 'L'acceptabilité sociale au bout de la transgression', *Vertigo - la revue électronique en sciences de l'environnement*, (Hors-série 34). doi: 10.4000/vertigo.30305.

* von Pechmann, F. et al. (2016) 'Comment prévoir le succès d'une innovation de rupture? Le cas du véhicule électrique', *Décisions Marketing*, 81, pp. 81–98. doi: 10.7193/DM.081.81.98.

* Pellerin-Carlin, T. and Serkine, P. (no date) 'De l'innovation participative pour une transition énergétique européenne compétitive', p. 6.

* Pénin, J. (2011) 'Open source innovation: Towards a

- generalisation of the open source model beyond software', *Revue d'économie industrielle*, n° 136(4), pp. 65–88.
- Pescia et al.: Un agenda pour une coopération franco-allemande en faveur de la transition énergétique en Europe, 1 Policy paper by D. Pescia, M. Gagnebin (Agora Energiewende), N. Berghmans (IDDRI), T. Pellerin.
- Peters et al., 2006: Peters, E, Västfjäll, D., Slovic, P., Mertz, C.K., Mazzocco, K., & Dickert, S. (2006). Numeracy and decision making. *Psychological Science*, 17, 407-413.
- Petric, 2010: Petric, R. (2010). A privacy-preserving Concept for Smart Grids. Sicherheit in vernetzten Systemen 18 B1 - B14. DFN Workshop. URL: https://www.researchgate.net/profile/Ronald-Petric/publication/230785976_A_privacy-preserving_Concept_for_Smart_Grids/links/0fcfd50bdf75e30674000000/A-privacy-preserving-Concept-for-Smart-Grids.pdf.
- * Piraux, M. et al. (no date) 'Le zonage à dire d'acteurs pour penser la gestion territoriale des ressources', p. 6.
- * Pivot, J.-M. and Raulet-Croset, N. (2005) 'Cadrages et projets de territoire dans les processus d'action locaux en faveur du patrimoine naturel', *Pyramides. Revue du Centre d'études et de recherches en administration publique*, (10), pp. 39–56
- Pohl et al., 2017: Pohl, C.; Krütli, P.; Stauffacher, M. (2017): Ten Reflective Steps for Rendering Research Societally Relevant. In: *GAiA* 26 (1), S. 43–51.
- Pointet, R., Erné-Heintz, V., Meyer, T. (2021). Messung der Sozialen Akzeptabilität einer Energieinnovation. Université de Strasbourg. URL: <https://seafire.unistra.fr/f/31e0a43de4c244e299e7/>
- Potier, 2019: Potier, F. (2019). Du lithium dans le sous-sol alsacien, *DNA*. URL: <https://www.dna.fr/economie/2019/03/19/du-lithium-dans-le-sous-sol-alsacien>
- * Production d'hydrogène: créer des écosystèmes territoriaux, développer une filière innovante (no date). URL: https://www.adcf.org/contenu-article-adcf-direct?num_article=6110&num_thematique=1&id_newsletter=485&source_newsletter=573&u=MTAxMQ.
- * Quéré, L. (1989) 'Les boîtes noires de Bruno Latour ou le lien social dans la machine', *Réseaux. Communication - Technologie - Société*, 7(36), pp. 95–117. doi: 10.3406/reso.1989.1354.
- Questionnaire 2021: "Nouvelles technologies vertes, énergie renouvelable et développement durable" by Kinnig, T., Chauvin, B. (2021). URL: <https://seafire.unistra.fr/f/7d1e0cf44a3644c8aa3b/>
- Reallabore, 2021: Bundesministerium für Wirtschaft und Klimaschutz website. Reallabore - Testräume für Innovation und Regulierung (2021). URL: <https://www.bmwi.de/Redaktion/DE/Dossier/reallabore-testraeume-fuer-innovation-und-regulierung.html>
- Regulation 2018/1999: Règlement (UE) 2018/1999 du Parlement Européen et du Conseil du 11 décembre 2018 sur la gouvernance de l'union de l'énergie et de l'action pour le climat. URL: <https://eur-lex.europa.eu/legal-content/FR/TXT/PDF/?uri=CELEX:32018R1999&from=EN>
- * Rejeb, H. B. (no date) 'Phases amont de l'innovation: proposition d'une démarche d'analyse de besoin et d'évaluation de l'acceptabilité d'un produit', p. 208
- Ribon et al., 2018: Ribon B., Badariotti D. et Kahn R. 2018. Fondements des analyses de flux de matières et d'énergie et typologies d'applications pour la gouvernance des territoires et des organisations. *Vertigo - la revue électronique en sciences de l'environnement*, Volume 18 numéro 2. DOI : 10.4000/vertigo.20822
- * Rogers, E. M. (1983) *Diffusion of Innovations*, 4th Edition. Simon and Schuster.
- * Rosental, C. (2009) 'Anthologie de la démonstration', *Revue d'anthropologie des connaissances*, 3(2), pp. 233–252. doi:10.3917/rac.007.0233.
- * Rosental, C. (2017) 'Les conditions sociales des échanges dans la Silicon Valley: comple militaro-industriel, entrepreneuriat scientifique et démos.', *Zilsel*, 1(1), pp. 55–81. doi: 10.3917/zil.001.0055
- Saqalli, 2015: Saqalli, M. et al. (2015). Backward waters, modern waters: Perception-Based Regional Mapping territory uses and water-related sanitary stakes in Luang Phabang area (Lao PDR), *Applied Geography*, Elsevier, pp. 184–193. Doi: 10.1016/j.apgeog.2015.04.001
- * Saucier, C. et al. (2009) Développement territorial et filière éolienne. Des installations éoliennes socialement acceptables: élaboration d'un modèle d'évaluation des projets dans une perspective de développement territorial durable. Report. Unité de recherche sur le développement territorial durable et la filière éolienne, rattachée au Centre de recherche sur le développement territorial (CRDT), Université du Québec à Rimouski. URL: <https://depot.usherbrooke.ca/handle/003300dd>
- Schäpke et al., 2018: Schäpke, N.; Stelzer, F.; Caniglia, G.;

- Bergmann, M.; Wanner, M.; Singer-Brodowski, M. et al. (2018): Jointly Experimenting for Transformation? Shaping Real-World Laboratories by Comparing Them. In: *Gaia* (27/S1), S. 85–96.
- * Shindler, B. and Brunson, M. (2004) 'Social acceptability in forest and range management', *Society and Natural Resources: A Summary of Knowledge*.
- SNCF, 2021: SNCF, 2021. Trains hydrogène: première commande lancée. URL: <https://www.sncf.com/fr/engagements/enjeux-rse/sncf-accelere-train-a-hydrogene>
- * Soland, M., Steimer, N. and Walter, G. (2013) 'Local acceptance of existing biogas plants in Switzerland', *Energy Policy*, 61, pp. 802–810. doi: 10.1016/j.enpol.2013.06.111.
- * Takam, E. N. (2021) 'Technologies de l'hydrogène comme vecteur de reconfiguration (géo)politique', *Vertigo - la revue électronique en sciences de l'environnement*, (Hors-série 34). doi: 10.4000/vertigo.30040.
- * Takeuchi, H. and Nonaka, I. (1986) 'Stop running the relay race and take up rugby', *Harvard Business Review*, p. 11.
- Tarascon et al., 2021: Tarascon, J.-M. 2021. « Batteries : Constituants, Évolution des recherches, Batterie 2030+. Le tout en 5 min. » Webinaire, avril 13. <https://www.concertation-acc-batteries.fr/compte-rendu-et-replay/7>.
- * Terrade, F. et al. (2009) 'L'acceptabilité sociale: la prise en compte des déterminants sociaux dans l'analyse de l'acceptabilité des systèmes technologiques', *Le travail humain*, Vol. 72(4), pp. 383–395.
- * Thévenot, L. (1993) 'Essai sur les objets usuels. Propriétés, fonctions, usages.', in *Les objets dans l'action*. Paris: Éditions de l'EHESS, pp. 85–111.
- * Thomson, I. and Boutilier, R. G. (2011) 'The Social License to Operate', in P. Darling (dir.), *SME Mining Engineering Handbook*. Society for Mining, Metallurgy and Exploration. Colorado, pp. 673–690.
- * Trompette, P. and Vinck, D. (2009) 'Retour sur la notion d'objet-frontière', *Revue d'anthropologie des connaissances*, Vol. 3, n° 1(1), pp. 5–27.
- Tumlison & Song, 2019: Tumlison, C., & Song, G. (2019). Cultural Values, Trust, and Benefit-Risk Perceptions of Hydraulic Fracturing: A Comparative Analysis of Policy Elites and the General Public. *Risk Analysis*, 39, 511-534. <https://doi.org/10.1111/risa.13197>
- * Turmel, F. G. R. (2021) 'Doit-on s'attendre à un refus du déploiement de l'hydrogène? Dynamique territoriale et transition énergétique', *Vertigo - la revue électronique en sciences de l'environnement*, (Hors-série 34). doi:10.4000/vertigo.30350
- * Vandelac, L. and Lemarchand, F. (2021) 'Introduction', *Vertigo - la revue électronique en sciences de l'environnement*, (Hors-série 34). Available at: <https://journals.openedition.org/vertigo/30100>
- Wanner et al., 2018: Wanner, M.; Hilger, A.; Westerkowski, J.; Rose, M.; Stelzer, F.; Schöpke, N. (2018): Towards a Cyclical Concept of Real-World Laboratories. A transdisciplinary research practice for sustainability transitions. In: *disP - The Planning Review* 54 (2), S. 94–114.
- * Wittmayer, J. and Hölscher, K. (no date) 'Transformationsforschung – Definitionen, Ansätze, Methoden', p. 125
- Zante, 2020: Zante, G (2020). Extraction de métaux stratégiques par une technologie de membrane liquide ionique supportée associée à des macrocycles: cas du lithium. Thèse Unistra, IPHC, p.234.
- * Zelem, M.-C. (2012) 'Les énergies renouvelables en transition: de leur acceptabilité sociale à leur faisabilité sociotechnique', p. 8
- ZSW-BW, 2020: Batteries: from the material to the product and back again, Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg, Extract from Annual Report 2020 (languages: EN, DE). URL: https://www.zsw-bw.de/fileadmin/user_upload/PDFs/Broschueren_und_Flyer/Schwerpunktbericht_2020_Batterien.pdf



Fessenheim Feasibility Study

Overview of The Pilot Projects



Funded by



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1. Competence Group Green Batteries and Circular Economy

1.1. Battery Materials Factory (BMF)

Competence Group:
Pilot name:

Green Batteries and Circular Economy
Pilot Project GB-BM-A "Battery Materials Factory (BMF)"

Justification for the pilot selection / Background

Background

Lithium-ion batteries (LIBs) are a key technology for electro-mobility whereby their 2nd life utilisation can also contribute to the expansion of renewable energy-sources, by providing large-scale electrical-energy storage. Additionally, LIBs are used in mobile devices that need electrical energy (laptops, mobile phones and so forth). However, the carbon footprint of the LIB production has to be further reduced, to fully use the potential for greenhouse-gas emission reduction regarding the replacement of technologies based on fossil fuels energy sources.

Justification

The production of battery materials – active as well as inactive supporting materials – is one of the steps during battery fabrication that needs a lot of energy and contributes therefore to the carbon footprint of LIBs. A pilot plant that deals with the production of these materials focusing on a reduced energy consumption is crucial in the future development of battery materials. Additionally, the upgrading of active materials from used batteries is a great possibility for further reducing the ecological impact of battery production. The production of new materials as well as the upgrading of used materials can be realised in the same facility, since the same steps are necessary.

Pilot key goals and actions

Goals and Actions

Producing state of the art materials for LIBs is the major purpose of this battery materials factory. However, the integration of recently developed materials into the production processes is also important and a goal of this facility. The following pilot projects are conceivable for this pilot plant:

- Development and fabrication of cathode active materials (CAMs) for LIBs

Producing state of the art CAMs that fulfill different requirements regarding their application should be the goal of this project. Especially NMC CAMs with a high content of nickel and a low content of cobalt (e.g., NMC811) as well as LiFePO₄ should be focused. Additionally the production of CAMs that are completely cobalt free (e.g., LiNi_{0.5}Mn_{1.5}O₄) should be included.

- Development and fabrication of anode active materials for LIBs

Next to the state of the art graphite materials for anodes, materials that also contain silicon should be produced. The incorporation of higher silicon contents can push the capacity of the anode materials.

- Development and fabrication of electrolytes and other supporting materials for LIBs

A production of materials with a low carbon footprint should be focused in this project

- Upgrading and fabrication of recycled battery materials for LIBs

This project is important for a circular economy of battery materials. Upgrading active material from used batteries has the potential to save large amounts of energy and reduce the carbon footprint of LIBs. Additionally it helps to become more independent from suppliers of the raw materials needed for the production of new active materials

Business and funding concepts

Industry partners should be encouraged to build the respective facility/ies.

To encourage these industry partners, the green battery group presents the advantages of the Fessenheim region to them

and shows the respective opportunities. With interested partners funding from the EU might be accessible to support these installations, since they fit very well to the goals of the European “green deal”.

Integration in the overall Regional Development Concept

For an extended utilisation of renewable energy-sources (RES) regarding the goal to provide electricity exclusively by RES, more electrical energy storage (EES) is required. Since batteries are one of the most promising technologies for this purpose, the development of sustainable materials for them, which is one goal of this pilot project, fits very well into the renewable energy concept of the region.

The other goal of this pilot project (upgrading of recycled battery materials) is an integral part of a circular economy regarding batteries. Therefore, this pilot also fits very well to this concept.

Supporting expert and industry groups

Research Institutes

- Albert-Ludwigs-Universität Freiburg (Germany)
- Fraunhofer ISE (Germany)
- Paul Scherrer Institut (Switzerland)
- EMPA (Switzerland)
- Université Haute-Alsace (France)

Possible Industry Partners

The following companies participated in a meeting where the plans for the innovation region Fessenheim were presented from the perspective of the “green batteries” group, but there are no compulsory arrangements or specific plans yet.

- BASF
- lolitec
- Freudenberg
- PCC

Next Steps

The three pilots Early Pilot Plant, Late Pilot Plant and a battery materials factory are interlinked.

The Early Pilot Plant will be the first, the Late Pilot Plant will then follow as a development, culminating in the construction of a battery materials factory.

SWOT analysis

<p>Strengths</p> <p>The demand for (sustainable) battery materials will grow. Even with a lot of competition on the market it is likely that the plant will be economically successful.</p> <p>The processes envisioned for this facility are established</p> <p>The river Rhine for transportation (very central location in Europe)</p> <p>Available expertise in the region</p> <p>Sustainability is an accepted topic and supported by a large share of the society</p>	<p>Weaknesses</p> <p>Not all the materials developed in this facility will become commercially interesting</p>
<p>Opportunities</p> <p>Take over a leading position for the development of sustainable battery materials worldwide.</p> <p>Become independent from critical raw materials (This also means to become independent from the countries that mine them)</p> <p>Jobs can be provided</p>	<p>Threats</p> <p>A lack of funding that is necessary for the participation of interested industry partners.</p>

1.2. Late Pilot Plant for Battery Materials

Competence Group:
Pilot name:

Green Batteries and Circular Economy
Pilot Project GB-BM-B "Late Pilot Plant for Battery Materials"

Justification for the pilot selection / Background

Background

The research in the field of new battery materials is an ongoing task, which was driven by improving the performance of the batteries in the last decades (higher energy density, higher power output, longer life cycles and so forth). Although these parameters are still important and need to be further improved, the focus is shifting towards "green" battery materials that are sustainable. Sustainability can be achieved by finding new materials based on respective elements as well as developing processes for their preparation that are less energy consuming.

Reusing active materials from used batteries can help to reduce the carbon footprint of lithium-ion batteries (LIBs). The upgrading of these materials that come from recycling is at its infancy and therefore holds a lot of potential to become a leading expert in this field.

Pilot key goals and actions

Goals and Actions

The major objective for this pilot plant is to further develop sustainable materials for batteries with a TRL from 7–9. For promising materials it is also important to find sustainable methods for their fabrication (e.g., preparation of cathode sheets), which is also a major goal followed by this pilot plant.

The following projects could be realised in a respective facility:

- Development and fabrication of CAMs for LIBs

Especially nickel-rich NMC CAMs with higher nickel contents than NMC811 are of interest. Nickel offers a high performance while being less problematic concerning abundance than cobalt. Completely cobalt-free CAMs like LiMn2O4

Justification

Almost every material that is used in a battery can be improved regarding sustainability e.g.: Cathode active materials (CAMs), anode active materials and all the inactive supporting materials. A pilot plant that deals with these topics holds a lot of potential for innovation regarding a sustainable energy sector, which is an important part of the European "green deal". It can clearly be stated that this pilot plant strongly promotes the long-term vision of an innovation region with the focus on sustainable development.

should also be within the scope of this project.

- Development and fabrication of anode active materials for LIBs

The utilisation of silicon in anode materials is a promising approach to increase the capacity while using a much more abundant and therefore sustainable element. Although anodes with small amounts of silicon are already commercially available, increasing this amount further is still problematic and more research is needed.

- Development and fabrication of electrolytes and other supporting materials for LIBs

Regarding the non-active supporting materials like electrolytes, binders, separators, conductive agents and all the components

of the casing, the focus should lie on more sustainable alternatives. As an example, it would be desirable to replace the fluorinated binder used for the preparation of the cathode sheets.

- Recycling of spent vanadium-based electrolytes for redox-flow batteries (RFBs)

Although the all-vanadium RFB struggles with a commercial breakthrough, due to the low availability of vanadium it is a very advanced and well-functioning technology. The all-vanadium RFB offers a very long life

cycle, high round-trip efficiencies and it is very safe due to the aqueous electrolyte. An effective recycling of the respective electrolyte is therefore an important topic.

- Upgrading and fabrication of recycled battery materials for LIBs

This project is important for a circular economy of battery materials. Upgrading active material from used batteries has the potential to save large amounts of energy and reduce the carbon footprint of LIBs. Additionally it helps to become more independent from suppliers of the raw materials needed for the production of new active materials.

Business and funding concepts

Industry partners should be encouraged to build the respective facility/ies.

To encourage these industry partners, the green battery group presents the advantages of the Fessenheim region to them

and shows the respective opportunities. With interested partners, funding from the EU might be accessible to support these installations, since they fit very well to the goals of the European "green deal".

Integration in the overall Regional Development Concept

For an extended utilisation of renewable energy-sources (RES) regarding the goal to provide electricity exclusively by RES, more electrical energy storage (EES) is strongly required. Since batteries are one of the most promising technologies for this purpose, the development of sustainable materials for them, which is one goal of this

pilot project, fits very well into the renewable energy concept of the region. The other goal of this pilot project (upgrading of recycled battery materials) is an integral part of a circular economy regarding batteries. Therefore, this pilot also fits very well to this concept.

Supporting expert and industry groups

Research Institutes

- Albert-Ludwigs-Universität Freiburg (Germany)
- Fraunhofer ISE (Germany)
- Paul Scherrer Institut (Switzerland)
- EMPA (Switzerland)
- Université Haute-Alsace (France)

Possible Industry Partners

The following companies participated in a meeting where the plans for the innovation region Fessenheim were presented from the perspective of the "green batteries" group, but there are no compulsory arrangements or specific plans yet.

- BASF
- Iolitec
- Freudenberg
- PCC

Next Steps

The three pilots Early Pilot Plant, Late Pilot Plant and a battery materials factory are interlinked.

The Early Pilot Plant will be the first, the Late Pilot Plant will then follow as a development, culminating in the construction of a battery materials factory.

SWOT analysis

<p>Strengths</p> <ul style="list-style-type: none">• The demand for (sustainable) battery materials will grow. Even with a lot of competition on the market it is likely that the plant will be economically successful• The processes envisioned for this facility are established• The river Rhine for transportation (very central location in Europe)• Available expertise in the region• Sustainability is an accepted topic and supported by a large share of the society	<p>Weaknesses</p> <ul style="list-style-type: none">• A big investment is necessary
<p>Opportunities</p> <ul style="list-style-type: none">• Take over a leading position for the development of sustainable battery materials worldwide.• Become independent from critical raw materials (This also means to become independent from the countries that mine them)• Jobs can be provided	<p>Threats</p> <ul style="list-style-type: none">• A lack of funding that is necessary for the participation of interested industry partners

1.3. Early Pilot Plant for Battery Materials

Competence Group:
Pilot name:

Green Batteries and Circular Economy
Pilot Project GB-BM-C "Early Pilot Plant for Battery Materials"

Justification for the pilot selection / Background

Background

The research in the field of new battery materials is an ongoing task, which was driven by improving the performance of the batteries in the last decades (higher energy density, higher power output, longer cycle life and so forth). Although these parameters are still important and need to be further improved, the focus is shifting towards "green" battery materials that are sustainable. Sustainability can be achieved by finding new materials based on respective elements as well as developing processes for their preparation that are less energy consuming.

The materials that are on the market right now contain a lot of cobalt and graphite, which are critical raw elements. It is not very likely that the increasing demand for batteries worldwide can be satisfied using

these materials. Therefore, it is important to investigate new, more sustainable materials at a low technological readiness level (TRL) to be prepared for this increasing demand.

Justification

Almost every material that is used in a battery can be improved regarding sustainability e.g.: cathode active materials (CAM), anode active materials and all the inactive supporting materials. A pilot plant that deals with these topics holds a lot of potential for innovation regarding a sustainable energy sector, which is an important part of the European "green deal". It can clearly be stated that this pilot plant strongly promotes the long-term vision of an innovation region with the focus on sustainable development.

Pilot key goals and actions

Goals and Actions

The major objective for this pilot plant is the development and characterisation of new, sustainable materials for batteries. Therefore, materials with a TRL from 1–6 are in the focus. For promising materials, it is also important to find methods for their fabrication (e.g. preparation of cathode sheets), which is also a major goal followed by this pilot plant.

Materials with a low TRL also include other battery technologies next to LIBs. Therefore, the following projects are suggested:

- Development and fabrication of CAMs for LIBs

CAMs that are solely based on the element manganese (e.g., LiMn_2O_4) should

be focused here. Due to its high abundance, manganese can be considered sustainable.

- Development and fabrication of anode active materials for LIBs

Elemental lithium is a very attractive material for anodes. Overcoming the problems associated with the deposition of lithium and the necessary solid electrolyte interface (SEI), an increase of the anode capacity by a factor of 10 is possible. In addition, anodes based solely on silicon are very promising, but a lot of research and development is still needed.

- Development and fabrication of electrolytes and other supporting materials for LIBs

Regarding the non-active supporting materials like electrolytes, binders, separators, conductive agents and all the components of the casing the focus should lie on more sustainable alternatives. As an example, it would be desirable to replace the fluorinated binder used for the preparation of the cathode sheets.

- Development and fabrication of new electrolyte formulations for redox-flow batteries

Redox-flow batteries (RFBs) are very promising for large-scale electrical energy storage (LS-EES). Since the energy density is not as crucial for LS-EES as for electromobility, other chemistries besides the lithium-ion chemistry can be used, which is important regarding the high demand for batteries (v.s.). Since the chemistry of the benchmark RFB is solely based on the rare element vanadium, alternative chemical systems are very interesting and should be investigated.

- Development and fabrication of post-Lithium batteries (organic materials, Al, Zn, Mg and so forth)

Although LIB chemistry will probably not disappear in the future, it is also necessary to develop materials that might surpass the performance of LIBs. Multivalent metals are especially promising because of their multi-electron reactions. Although the energy density of organic materials falls behind at the moment, they can be charged extremely fast, and they are also interesting regarding sustainability.

Business and funding concepts

Industry partners should be encouraged to build the respective facility/ies

To encourage these industry partners, the green battery group presents the advantages of the Fessenheim region to them

and shows the respective opportunities. With interested partners funding from the EU might be accessible to support these installations, since they fit very well to the goals of the European “green deal”.

Integration in the overall Regional Development Concept

For an extended utilisation of renewable energy-sources (RES) regarding the goal to provide electricity exclusively by RES, more electrical energy storage (EES) is strongly required. Since batteries are one of the most promising technologies for this purpose, the development of sustainable materials for them, which is one goal of this

pilot project, fits very well into the renewable energy concept of the region.

The other goal of this pilot project (upgrading of recycled battery materials) is an integral part of a circular economy regarding batteries. Therefore, this pilot also fits very well to this concept.

Supporting expert and industry groups

Research Institutes

- Albert-Ludwigs-Universität Freiburg (Germany)
- Fraunhofer ISE (Germany)
- Paul Scherrer Institut (Switzerland)
- EMPA (Switzerland)
- Université Haute-Alsace (France)

Possible Industry Partners

The following companies participated in a meeting where the plans for the innovation region Fessenheim were presented from the perspective of the “green batteries” group, but there are no compulsory arrangements or specific plans yet.

- BASF
- Iolitec
- Freudenberg
- PCC

Next steps

The three pilots Early Pilot Plant, Late Pilot Plant and a battery materials factory are interlinked.

The Early Pilot Plant will be the first, the Late Pilot Plant will then follow as a development, culminating in the construction of a battery materials factory.

SWOT analysis

<p>Strengths</p> <ul style="list-style-type: none">• The processes envisioned for this facility are established• The river Rhine for transportation (very central location in Europe)• Available expertise in the region• Sustainability is an accepted topic and supported by a large share of the society	<p>Weaknesses</p> <ul style="list-style-type: none">• Development of new materials might not be successful
<p>Opportunities</p> <ul style="list-style-type: none">• Take over a leading position for the development of sustainable battery materials worldwide.• Become independent from critical raw materials (This also means to become independent from the countries that mine them)• Jobs can be provided• The demand for sustainable battery materials will grow and even with a lot of competition on the market, it is likely that the plant will be economically successful	<p>Threats</p> <ul style="list-style-type: none">• A lack of funding that is necessary for the participation of interested industry partners

2. Sub-Pilots: 2nd-life Subgroup

2.1. Robust and Resilient Supply Chain for EV Battery Recycling

Competence Group:
Pilot name:

Green Battery Circular Economy
Pilot Project GB-SL-A "Robust and Resilient Supply Chain for EV Battery Recycling"

Justification for the pilot selection / Background

The market for electric vehicles (EVs) is among the fastest growing energy-demanding markets. The batteries of EVs can be used for a limited time (or number of uses) and will then need to be changed. However, these exchanged batteries remain functional and offer a storage capacity that can be used to extend their lifetime. Moreover, not all the batteries that are taken out of EVs can be used for electricity storage. Some batteries are removed because of damage and have to be recycled. Reusing and recycling EVs batteries therefore constitute a great challenge that needs to be addressed.

Used batteries are collected from different "collection points" (car manufacturers, dealer shops, etc.). Batteries are then qualified to evaluate whether they can be

used for storage in their "2nd life". If they are ready, these batteries are used in residential and industrial buildings for energy storage (energy generated locally). They can also be used in storage plants for large-scale energy storage. If they are not suitable for use, they are shipped to recycling plants.

A supply chain network needs to be studied and put in place. This supply chain needs to take into account several parameters and constraints: transportation means (road, air, river, etc.), types of collection points, location of qualification centres, regulations for EV batteries, environmental constraints among others. The supply chain will also integrate one or several battery recycling plants and storage plants.

Pilot key goals and actions

The main objective of this pilot project is to investigate several EV battery recycling supply chain scenarios in which one or several recycling and storage plants are considered. To do so, the following aspects will be considered:

- Identify and study qualification plant locations depending on demand for used battery energy, capacity and regulations for EV transportation
- Investigate how the different transportation means can be combined for EV battery transportation and the cent-

ral location of Fessenheim for a global European supply chain network of EV battery recycling

- Identify and optimize the new recycling plant locations across Europe while taking into account different constraints (current plants and their capacities, collection points, EV market share, etc.)
- Establish an economic evaluation for the different scenarios for different time horizons (2025, 2030, 2040 and 2050)

Business and funding concepts

Several funding organisations have shown interest and published calls for projects on the topic. The following organisations will be solicited for this project:

- European council (EU)
- Agence Nationale de Recherche (FR)
- ADEME (FR)
- PIA4 (FR)

- BPI (FR)
- Grand Est Region (FR)
- Baden Württemberg Land (DE)
- VDE/VDI (DE)
- BMU (DE)
- BMBF/BMWI (DE).
- Moreover, several companies have shown interest

Integration in the overall Regional Development Concept

This project will contribute to the ongoing effort of creating a European supply chain of EV battery recycling. The market is still young and as the EV market share grows, so does the recycling market. The International Energy Agency expects that the EV market share will strengthen during the upcoming decade creating thus a strong demand for EV battery recycling supply chain.

The reuse and the recycling of EV batteries will have a two-fold impact on the region:

- Storage plants will allow the storage of energy generated using renewable sources reducing thus the share of fossil and nuclear sources

- Strengthen the recycling EV batteries industry to reach worldwide impact
- Contribute to the ongoing effort of creating a European industry and supply chain of EV battery recycling supporting the circular economy
- Increase renewable energy storage capacity using storage plants and reduce thus the share of fossil and nuclear sources
- Contribute to improving EV battery qualification and transportation regulations across Europe

Supporting expert and industry groups

Research Institutes

- Troyes' Institute of Services and Industries of the Future
- Lorraine University
- Fraunhofer IML
- Fraunhofer ISE
- Fraunhofer IWKS

Possible Industry Partners

- Tech3D France
- BASF
- Opta LP
- MobEnergy

Moreover, ongoing discussions are currently held with the following companies to join the project

- Veolia Euro Dieuze Industrie
- BMW
- Peugeot
- EDF
- DHL

Next steps

The plan for the 2nd life subgroup consists of two steps. First, a qualification centre for 2nd life EV-batteries is needed. This will have to be established first, so that batteries can be assessed before being used for energy storage.

Second, a utility-scale hybrid electrical energy storage that is complemented by 2nd life batteries need to be put into place.

SWOT analysis

<p>Strengths</p> <ul style="list-style-type: none">• A growing demand• An already initiated industry• Several means of transportation	<p>Weaknesses</p> <ul style="list-style-type: none">• Limited number of recycling plants• Limited regulations for EV battery transportation• Manufacturer-based collection of EV batteries
<p>Opportunities</p> <ul style="list-style-type: none">• Solid knowledge on EV battery recycling• A worldwide demand for EV battery recycling• A strong effort from OEMs for the industry	<p>Threats</p> <ul style="list-style-type: none">• Integration of storage plants to electric networks• A limited capacity for a strong demand for recycling

2.2. Concept for a dismantlement plant for used EV batteries

Competence Group:
Pilot name:

Green Battery
Pilot Project GB-SL-B "Concept for a dismantlement plant for used EV batteries"

Justification for the pilot selection / Background

A used battery system is not necessarily intended for recycling only. The evaluation of a 2nd life is recommended for sustainability at least on system and module level. In case of recycling and 2nd life a dismantling of the battery system is necessary. The automation of the battery disassembly, in

particular for Li-Ion-batteries is crucial for several reasons like safety and efficiency. For safe operation, the electric state of the battery system and the modules have to be checked and controlled in the process. However, this task is not yet solved.

Pilot key goals and actions

Two alternative automated process concepts for safe battery disassembly:

- Robust Disassembly: Opening process for battery systems with robot-controlled waterjet cutting incl. water cooling, process water filtration (Description: cutting tests, optimisation of abrasive cutting, water cooling)
- Smart dismantling for reuse of various parts: individual non-destructive removal of the battery parts, using machine learning, integration of fast analysis methods, product data, etc.

- Intelligent and adaptive disassembly planning
- Layout planning for adaptable and flexible disassembly factories

A concept for decommissioning will be developed for safe handling of end-of-life systems or components, including material safety/ performance testing, discharging, safe transport, safe storage. Crucial steps:

- EoL-battery system
- EoL-module
- EoL-cell

Merging of both approaches into an optimal process: Combination of most promising steps of each process route.

Business and funding concepts

Consortium with a big partner as final owner/operator of a disassembly plant, permanent suppliers and R&D partners for

further development and expansion. Option: public funded project on EU level (Horizon)

Integration in the overall Regional Development Concept

Disassembly is a crucial step linking the end-of-1st -life battery and the two routes "2nd life" and "recycling". In the big context this is an important part of the circular economy, since an efficient and safe disas-

sembly / dismantling enables sustainable use and reuse of non-critical and critical materials, which is the basis for an entire economic and ecological energy concept.

Supporting expert and industry groups

- Fraunhofer IWKS (Recycling technologies, Waterjet cutting)
- Fraunhofer ISE, Fraunhofer IPA (automation, digitalisation, layout planning, disassembly strategies)
- LGIPM Laboratory/Univ. Lorraine (Automation with waterjet cutter / Robotics - Cobotics, Process digitisation)
- Knoll
- Storion
- Hydac International GmbH (Watercooling, process water filtration)
- Knoll Feinmechanik GmbH (Automation)

Supporting expert and industry groups

The plan for the 2nd life subgroup consists of two steps. First, a qualification centre for 2nd life EV-batteries is needed. This will have to be established first, so that batteries can be assessed before being used for energy storage.

Second, a utility-scale hybrid electrical energy storage, that is complemented by 2nd life batteries need to be put into place.

SWOT analysis

<p>Strengths</p> <ul style="list-style-type: none"> • Increase of Recovery rate for almost all fractions • Enabling reuse/2nd life • Crucial requirement for the following recycling steps regarding the need for high quality output fractions (in particular black mass or electrode precursors respectively) 	<p>Weaknesses</p> <ul style="list-style-type: none"> • Automated dismantling relies on data about individual products • Safety assessment crucial for every battery type • Individual training of robot process
<p>Opportunities</p> <ul style="list-style-type: none"> • Improved throughput for expected high backflow of EoL-batteries • Safe process with minimized manual labor 	<p>Threats</p> <ul style="list-style-type: none"> • The economic efficiency might not reach that of a manual dismantling for small numbers

2.3. Methods for qualification of used battery systems, modules and cells

Competence Group:
Pilot name:

2nd-life battery on the grid
Pilot Project GB-SL-C "Methods and deployment challenges for qualification of used battery systems, modules and cells (safety, reliability, performance)"

Justification for the pilot selection / Background

The goal is to apply the new European policies concerning the regulation of batteries, while making sure that batteries (placed in the EU market) are sustainable and safe throughout their entire life cycle.

The sustainability and competitiveness of battery value chains need to be ensured (ensure durability and minimum electrochemical performance/energy performance requirements).

Also, the scheme for battery collection, refurbishing, reusing, and recycling activities

will have to be optimized, along with the identification of the requirement for battery classification for the 2nd life applications. Additional requirements of monitoring efforts and decision support for reuse and recycling industries exist.

All the while, safety, data record, labelling and end-of-life management requirements for rechargeable batteries must also be considered.

The pilot contributes to the promotion of SDGs 7, 8, 9, 12, 13 and 17 of the UN.

Pilot key goals and actions

Main objective

Methods and integration of run-time /dynamic monitoring of states and lifetime supervision of batteries (performance, safety, and reliability) and fast lab-based verification strategies for the qualification for 2nd life applications

Goal 1: Durability and minimum electrochemical performance requirements

- Action: Identification of current performance, prediction of future performance and aging behaviour of batteries

Goal 2: Safety requirements

- Action: Tests and diagnosis of safety and reliability of battery systems

Goal 3: Labelling and information requirements

- Action: Smart battery management for monitoring, control, localisation, and tracking

Business and funding concepts

Through providing the monitoring and labelling of batteries for large European geographic areas and providing a networked data platform service for communication, identification, composition, and information of states of 1st life batteries for 2nd life battery industries, economical value can be added.

Customer and industrial service applications for collecting (support for organizing the logistics), refurbishing, reusing in 2nd life applications and recycling of batteries are additional possibilities with business cases.

Integration in the overall Regional Development Concept

- Strong impact in system integration of fluctuating renewable energies in the region by using 2nd life batteries as energy storage
- To ensure truly circular lifecycles for traction batteries, and to harness the

opportunities for growth and jobs in the region

- To propose a platform for interactions with and between key industrial partners.

*Supporting expert
and industry groups*

LCOMS

is a multidisciplinary laboratory which specialises in the development of embedded computer systems, smart networked multi-sensors with expertise for large applications such as smart renewable energy management, battery management systems (BMS), IoT systems and real time data security exchanges.

TDF Infrastructure SAS

is a company that specialises in connectivity and communication infrastructure. For radio and DTT broadcasting, mobile ultra-high-speed broadband coverage and rolling out optical fibre, TDF brings clients in-depth operational expertise, a mix of unique and ground-breaking technology and an exceptionally widespread local presence. In an ever more connected world, over the last four decades or more TDF has enabled telecoms and media companies to connect the French regions and people everywhere and faster.

BENNING CMS Technology GmbH

is a company which specialises in the new development of battery management systems (BMS) and their technical imple-

mentation for lithium battery systems. This expert company has since patented two revolutionary processes for lithium battery system operation which are more efficient and economical, and which better preserve the battery system.

The Fraunhofer Institute for Solar Energy Systems

creates the technological foundations for supplying energy efficiently and based on an environmentally sound basis in industrialised, threshold and developing countries. This expert research institute focuses on energy conversion, energy efficiency, energy distribution and energy storage, it contributes to the broad application of new technology.

Research at the Institute of Energy Systems Technology

(Hochschule Offenburg) focuses on investigations and development of systems for sustainable energy use. This institute is expert in research-and-development about smart grids, building energy technology, battery technology, photovoltaics, hydrogen technology, energy economics, and electromobility.

Next steps

First, a development phase for methodology, networks communication and electronic exchange is needed. Following, tests and further development are neces-

sary, before an implementation can be discussed. After an initial Beta release, the final result can be released as a project.

SWOT analysis

<p>Strengths</p> <ul style="list-style-type: none">• Favorable European legislation• Capacity for innovation• Technology competitiveness (Innovation of BMS, data monitoring for the management and the 2nd life)• Highly qualified employees• Strong economic activity• No required construction and industrial infrastructure (already exist)	<p>Weaknesses</p> <ul style="list-style-type: none">• Low financial capacity• Dependence on battery and BMS manufacturers and their willingness to provide access to BMS data• Competence for client and industrials /manufacturers databases exist
<p>Opportunities</p> <ul style="list-style-type: none">• Fast growing market• Promote new technologies• Optimize the circular economy for batteries and sourcing of raw materials• Provide classification of batteries• Change user and consumer behaviours• Contribute to addressing to diligence obligations of companies for the supply chain of recycled raw materials• Contribution to reduction of carbon footprint• Reduction of environmental impact	<p>Threats</p> <ul style="list-style-type: none">• Increasing costs due to technological innovation (in the beginning)• Emerging competitors• Evolution or changing in demand

2.4. Methods and control strategies for predicting and increasing remaining useful life- time in 2nd life applications

Competence Group:
Pilot name:

Green Battery Circular Economy
Pilot Project GB-SL-D "Methods and control strategies for managing (prediction & control) the remaining useful life-time of the Fessenheim 2nd life Battery for optimized operation"

Justification for the pilot selection / Background

The integration of used car batteries (1st life) into stationary 2nd life battery applications has a great potential.

However, it requires a deep understanding as well as reliable prediction of the remain-

ing useful lifetime (RUL) of the battery for this non-native EV battery usage. This development is crucial to succeed with a commercially viable integration and safe and efficient long-term operation of 2nd life battery plants.

Pilot key goals and actions

Therefore, the following key goals and actions are addressed:

- Identification of possible operational risks and corresponding mitigation of these
- Deepening the profound understanding of the non-native application specific behaviour of EV LIB by behaviour modelling and model-based diagnostics
- Development of application dependent health indicators, such as "state-of-energy/life", as a reliable key indicator of the RUL

- Guidelines and standards on safe and economic operation as well as possibilities of optimisation of long-term operations of 2nd life battery plants
- Gaining long term experience on safe and commercial operations by intensive monitoring and a closed loop optimisation of the corresponding key indicators with field data

Business and funding concepts

The development of a KPI is crucial for a successful and efficient operation of 2nd life batteries, but unfortunately not of interest to one particular company or industry section. For this reason, financing from the industry is difficult and it will require funding support of a superior entity such as the EU.

- Budget estimate: (total: 3 m. €)
- Model based diagnostics: 0,8 m. €
- Laboratory characterisation: 0,7 m. €
- Development of the KPIs: 0,5 m. €
- Monitoring and operational optimisation: 1 m. €

Integration in the overall Regional Development Concept

Keeping the lifetime extension and the minimisation of the carbon footprint of lithium-ion batteries (LIB) in mind, stationary 2nd life battery plants will play a key role in the increase of renewable energies and the energy transition for Europe.

Apart from the overarching significance for Europe, the work in this pilot proposal will be seamlessly interlocked with its partner pilot (2nd life demonstration plant set-up and integration) and is required to secure a sustainable and long-term usage as well as secure and safe operation in this light for a circular battery economy.

Supporting expert and industry groups

Research Institutes

- Université de Lorraine (FR)
- UAS FHNW (CH)
- UAS Offenburg (DE)
- Fraunhofer ISE (DE)

Possible Industry Partners

- Stellantis (PSA)
- possibly other OEMs

Next steps

The Project content can be divided into two parts, on the one hand the general research and development of the KPI for RUL and on the other hand the integration and operational optimisation of the partner pilot in Fessenheim. The first part can be started almost immediately, but the second part will require interaction with the other pilots, and therefore a reconciliation between the pilots is strongly recommended. The attached Gantt chart is only an exemplary pathway starting by 2022.

It outlines four major phases that are sequential with significant overlap between steps.

First, model based diagnostics need to be employed to enable laboratory characterisations in a second step. Third, the relevant KPIs will be developed. Finally, monitoring and optimisation is needed.

SWOT analysis

<p>Strengths</p> <ul style="list-style-type: none"> • Long track record and experience in battery state estimation and characterisation • High-end battery laboratories for testing and characterisation of battery cells and packs • World excellence and reputation of the scientific partners • Well-founded monitoring and characterisation know-how of LIB cell to multi-MW battery power plants 	<p>Weaknesses</p> <ul style="list-style-type: none"> • 1st life might have a significant influence, that standardisation (with KPI for RUL) will be difficult
<p>Opportunities</p> <ul style="list-style-type: none"> • Regional presence of OEMs (such as Stellantis or Daimler) to support development of KPIs during 1st life • Chance of developing a widely agreed KPI / standard for the identification of the RUL 	<p>Threats</p> <ul style="list-style-type: none"> • Availability of EV batteries (Stellantis) • Missing information (cycles, environmental stress) from 1st life can influence predictions quality

2.5. System set-up and grid integration of 2nd life storage Modular design, installation, grid-connection and safety concept

Competence Group:
Pilot name:

Green Battery Circular Economy
Pilot Project GB-SL-E "2nd life demonstration plant set-up and integration"

Justification for the pilot selection / Background

Implementation of a demonstrator grid battery consisting of 2nd life battery units, which are connected to the electricity transmission grid in Fessenheim. This approach has the following advantages:

- The demonstrator showcases the behaviour of a larger grid battery that can later be installed at the same location
- The existing electrical infrastructure at the former nuclear power plant (NPP) at Fessenheim is an ideal location for a large grid-stabilising storage device
- The proposed demonstrator can be used for grid and battery studies of the

participating universities and research institutions

- The participating industry partners can develop and test new product generations. Their success guarantees the generation of new high-technology jobs in the region
- The usage of 2nd life batteries for the proposed demonstrator plant links this activity with the other steps (dismantlement, qualification, decommissioning of 2nd life batteries...) in the value chain

Pilot key goals and actions

The goal of this activity is the design and installation of a medium-size (10...50 MW) grid battery at the site of the former Fessenheim Nuclear Power Plant (NPP). This battery will serve as a demonstrator plant for a larger storage power plant that can later be constructed at this site, allowing for the stabilisation and energy balancing at this central node of the European electricity grid.

The grid battery is assembled out of individual 2nd life lithium battery packs. There-

fore, an important task is the development of a safety concept for handling and operation of 2nd life batteries. A novel battery converter concept that can handle batteries of varying types and states at the same time will be developed. Additionally, this battery converter can be of the grid-forming type, a control technology that allows for the reliable operation of electricity grids even in the case of very high renewable energy penetration, thereby reducing the need for conventional must-run units.

Business and funding concepts

Since a large part of the components of the demonstrator battery are not yet commercially available but require research and development by the participating partners, public funding (preferably via EU projects) is obligatory to support its realisation. While the research partners need full support, the industry partners can contribute by shouldering a share of their individual expenses.

In the long run, the demonstrator battery can create income by participating in the electricity balancing market, which will contribute to covering the operating costs.

Expected budget:

- Construction of 2nd life grid battery demonstrator: 1,5 m. €
- Development of adapted battery converter for 2nd life batteries: 2,5 m.€
- Safety and operation concept development, grid connection and grid integration: 1 m. €

Integration in the overall Regional Development Concept

- Fraunhofer Institute for Solar Energy Systems ISE, Freiburg, Germany
- Institut National des Sciences Appliquées (INSA) Strasbourg, Strasbourg, France
- ASD Automatic Storage Device GmbH, Umkirch, Germany
- TRICERA energy GmbH, Bobritzsch-Hilbersdorf, Germany
- Hitachi ABB Power Grids (Requested)

Next steps

The development of a battery converter has to begin first and following, construction of the demonstrator can begin in parallel. The safety concept, grid connection and integration are the last steps in the process.

SWOT analysis

<p>Strengths</p> <ul style="list-style-type: none"> • Strong industry and research partners present in the greater region of Fessenheim • Ideal location • Strong industry support • Low environmental risk 	<p>Weaknesses</p> <ul style="list-style-type: none"> • Business case depends on support through public funding
<p>Opportunities</p> <ul style="list-style-type: none"> • Integration of novel, yet partly proven technology in a demonstrator plant • Possibility to test and compare different battery technologies • Showcase room for novel industry solutions 	<p>Threats</p> <ul style="list-style-type: none"> • Lack of political support • Support of Fessenheim NPP's owner EDF not yet confirmed • Full integration in grid operator's power management desirable for full usefulness

2.6. Grid-Scale Carnot Battery Technology Platform

Competence Group:

Green Battery Circular Economy

Pilot name:

Pilot Project GB-SL-F "Grid-Scale Carnot Battery Technology Platform"

Justification for the pilot selection / Background

The demonstration of 300 000 kWh thermal battery modules (Carnot battery) is proposed to provide long-term storage capacity for the electricity grid – an industry-driven approach backed by companies from Germany, France and Switzerland.

The Carnot Battery

The term Carnot Batteries refers to energy storage technologies based on the power-to-heat-to-power principle. Electricity is converted to heat and is stored as thermal energy, which can be done in inexpensive, environmentally safe materials, such as rocks or molten salt. The low cost of the storage material allows for mid- to long-term energy storage. To date, many different Carnot battery concepts are being pursued in different industrial contexts, but it is not yet clear which concept would offer the most favorable economic and ecological performance.

Usefulness of a Carnot Battery in the Innovation Region Fessenheim (IRF)

- Carnot batteries have a large and relatively inexpensive storage capacity. Installed at electrical grid nodes like Fessenheim, they have the ability of en-

abling load shifting at high-power level for periods of several hours or days. They are therefore an essential building block in the creation of a cross-border energy system with fluctuating supply.

- CNRP Fessenheim is a thermal power plant – many already existing assets can be reused on the site through the proposed pilot.
- Synergies with other planned actions: electrical batteries (for short-term storage), smart grid, district heating network. Thermal batteries are more suited to cost-effectively serve a relatively continuous load over an extended period of time. Thermochemical batteries have a very short response time to a sudden and short-term rise in electricity demand. These advantages of storing energy in electric batteries typically come with the disadvantage of a higher cost per energy.
- The IRF will serve as a technology platform for grid-scale electricity storage. The set-up of different large-scale pilots in a representative environment enables the identification of the most appropriate technology. This will allow a scale up of the technology – both at the IRF and at other sites.

Pilot key goals and actions

- Setup of 3 Carnot Battery systems, based on different technologies
- Demonstration of technological readiness of the Carnot Battery concept in a representative industrial-scale environment
- Prove economic viability to investors, stakeholders and decision-makers, in order to stimulate and incentivize replicated design at other sites
- Provide technological and operational knowledge for future large-scale projects
- Create a research platform for the participating international industry partners and research institutes
- Establish technical know-how of a technology with expected market potential for the near future in the IRF
- Promote cross-border cooperation in the development of an essential component for the future European energy system

Business and funding concepts

Under the expected future energy market conditions, operation of a Carnot battery over its total lifetime of 25-40 years is likely to be economically feasible.

Therefore, there is a certain interest from private investors who can provide partial funding.

However, the initial cost of building a Carnot battery is very high, followed by very low operating costs and stable yield. Since very few large-scale projects have been tested over a long period of time, the

investment risk is currently considered too high for full private financing. Expected budget:

- Construction of 3 storages: 9 m. € each
- 3 Charging/discharging units: 11 m. € each
- Civil works, power electronics, commissioning and monitoring: 3 m.€ each
- Overall Budget: 69 m.€

Integration in the overall Regional Development Concept

The possibility to store electrical energy as heat optimally complements the generation of electricity from renewable energy sources and battery storage. The added possibility of using heat or waste heat supplied to private and industrial consumers within a district heating network is a major advantage of the Carnot Battery concept. The resulting coupling of different sectors in the region would lead to a substantial

increase in energy efficiency and flexibility. Storage of electrical energy as heat fits inherently into the circular economy concept, as for the storage material, no scarce raw materials must be consumed. For the operation of the battery, no inflow of any raw material is necessary. In addition, the continued use of existing infrastructure becomes possible, which would otherwise have to be dismantled.

Supporting expert and industry groups

Research Institutes

- Fraunhofer ISE (DE)
- CEA (FR)

Possible Industry Partners

- Enolcon + large German utility (DE)
- MAN-ES (CH, DE)
- Bouygues Construction (FR) + Kraftanlagen München (DE)
- Potential additional Partners: Siemens (DE)
- GE (FR)
- Atlas Copco (FR)

External expert group

IEA TCP Energy Storage Task 36 – Carnot Batteries (15 countries; 56 participating organisations from industry, academia and government agencies)

Next steps

<p>2022: Specification of the technological concept and detailed dimensioning of the pilots, planning of integration of the new infrastructure in the dismantling of the current infrastructure</p> <p>2023: Clarification of the funding, acquisition of private investors</p>	<p>2024-2026: Construction phase</p> <p>2027: Commissioning and testing</p> <p>From 2028: Regular operation, long-term monitoring and service to the electric grid</p>
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SWOT analysis

<p>Strengths</p> <ul style="list-style-type: none"> • Very low cost of the storage material • Increased lifetime of storage medium • Possibility of using existing infrastructure on-site 	<p>Weaknesses</p> <ul style="list-style-type: none"> • Relatively low efficiency • High price of the power unit
<p>Opportunities</p> <ul style="list-style-type: none"> • Need for research with regard to efficient and uniform feed of energy into the storage medium and withdrawal of heat at high power levels • Development of energy storage systems with low-cost storage media is therefore an economically promising opportunity • Major economic opportunities of the concept exist if fluctuations in the electricity price remain high 	<p>Threats</p> <ul style="list-style-type: none"> • A local risk potential exists only due to the high temperature of the storage material. Environmental risks due to the release of harmful materials do not arise. • Smoothing of energy prices threatens economic feasibility

2.7. System integration: 2nd life, NaS battery, Redox-flow battery, Carnot battery

Competence Group:
Pilot name:

Green Battery Circular Economy
**Pilot Project GB-SL-G "System integration of the Hybrid storage:
2nd life Li-Ion battery, NaS battery, Redox-flow battery, Carnot battery"**

Justification for the pilot selection / Background

Integration of used EV batteries, which are usable for 2nd life application, into a hybrid storage system. Implementing an intelligent energy management system (EMS) to operate the innovative battery storage in

an economic way and support the grid with grid services. This pilot is one key factor to support the stability level with 100% renewable energies in the system.

Pilot key goals and actions

The key goals of the pilot group are listed in the following lines:

- integrate different battery storage technologies economically into the system
- developing an energy management system (EMS) for the hybrid storage
- monitoring the hybrid system (especially the 2nd life battery in acting with the other battery systems) for better

optimisation

- qualify the overall hybrid battery system
- develop and integrate quality assurance system for a save operation for the 2nd life battery
- For this pilot a TRL 7 can be reached.

Business and funding concepts

The pilot project needs funding support for implementation of this lighthouse as well as for the development of the energy management system and the implementation, test and evaluation of the hybrid battery system. Therefore, the pilot needs following funding (budget estimate):

- NAS – battery (BASF): 1,5 m. €
- Redox Flow battery (Storion): 1,5 m. €

- Grid Integration & Hybrid Battery Management (EMS): 2 m. €
- Note: Budget for 2nd Life and Carnot battery are already included in the corresponding tasks
- The long-term target will be that the battery will cover the operating costs without external funding.

Integration in the overall Regional Development Concept

With the integration of different battery technologies, companies around the greater Fessenheim area like BASF, Stellantis (PSA) or Storion can integrate and validate the battery systems and can build up their expertise with the lighthouse technologies for the way towards the

European goal of climate neutral by 2050. Out of this pilot project jobs, experience, greater knowledge and connectivity between the different stakeholders can be created. Due to this extraordinary process the whole region will benefit.

Supporting expert and industry groups

Research Institutes

- Fraunhofer ISE
- University of Strasbourg
- University of Freiburg

Possible Industry Partners

- BASF
- Storion
- Enolcon
- Kraftanlagen München / Bouygues Construction
- MAN-ES
- Stellantis (PSA)

Next steps

The developed roadmap is highly dependent from the start of the project and the progress of the other pilot projects of the Competence Group: 2nd life battery on the grid.

The overall project comprises five processes. The integration of different battery storages, the development of an energy management system, the monitoring of the hybrid system, the qualification of the system and permanent project management.

SWOT analysis

<p>Strengths</p> <ul style="list-style-type: none">• High engineering experience in the field of storage technologies, energy management systems (EMS) and innovative battery technology solution• Long-term experience in monitoring and analyzing and optimizing of field power plants• Well experienced in implementing hybrid battery storage technologies• Very strong consortia: High research excellence combined with very good and strong support from industrial partners	<p>Weaknesses</p> <ul style="list-style-type: none">• Language barriers• Bureaucratic structure
<p>Opportunities</p> <ul style="list-style-type: none">• This lighthouse project will have a significant radiance in the field of green energy to reinforce the leadership and reputation for the upper Rhine valley in being a frontrunner of the energy transition• Creating an infrastructure which will create jobs in a future leading technology sector• Growing public interest of the topic, because of the energy transition	<p>Threats</p> <ul style="list-style-type: none">• Support of network operator and site owner (EDF) not yet confirmed• Availability of 2nd life batteries (Stellantis)• Potential bigger safety standard for the battery

3. Sub-Pilots of the Battery Recycling Subgroup

3.1. Dismantlemen

cf. "Sub-Pilots: 2nd life Subgroup: Robust and Resilient Supply Chain for EV Battery Recycling" Pilot Sheet

3.2. Recyclate analytics and qualification

Competence Group: **Green Battery**
Pilot name: **Pilot Project GB-BR-A "Concept for recyclate analytics and qualification"**

Justification for the pilot selection / Background

Current recycling processes focus on the recovery of the valuable metals such as Ni, Co, Mn, etc. to reach future recycling rates the industry needs to focus as well on the recycling of other materials. Using materi-

als recovered from production or EoL waste will lead to the necessity of proper material testing and quality assurance within both R&D and production.

Pilot key goals and actions

Recyclates (regenerated electrode materials or precipitated starting compounds from production or End of Life waste) need to be qualified for a further use in batteries according to specifications that need to be defined together with the other tasks in this project.

- In general standard methods and measures are needed to provide the most precise picture of the material performance and composition and assure transparent and reliable material provision throughout the material cycle. Therefore, following key goals and actions will be addressed:

- Development and definition of methods for recyclate (from production and EoL) analytics. Therefore amongst others the following methods might be applied to analyse materials and their properties: Elementary analysis, ICP-OES, Particle classification and characterisation (size, mash-width, ...), XRD, REM-EDX, TGA, DSC,...
- Development of an evaluation process for recyclates
- Definition of certification measures for a defined process to meet materials standards

Business and funding concepts

Must be aligned with general development concepts.

Integration in the overall Regional Development Concept

Battery development and production is driven by high performance concerning capacity, energy density and lifetime. For a circular economy and a sustainable implementation of renewable energy concepts it is mandatory to qualify recyclates for the use in new batteries to keep the high standard of state-of-the art batteries. To-

gether with innovative disassembly and recycling processes and cell production recyclate analytics offer the opportunity for the implementation of an analytics lab with researchers and technicians in the region of Fessenheim with the requirement to constantly adapt to new developments in the field batteries.

Next steps Will be aligned with other tasks as the methodology of qualification will depend on the recovered materials.

For proper usage, both a facility for battery dismantlement and a facility for the recycling of battery materials are needed.

SWOT analysis

<p>Strengths</p> <ul style="list-style-type: none"> • The need for battery material qualification will constantly increase due to ongoing development in the field of batteries • Will be a basic need to enable a re-introduction of any kind of materials back into batteries 	<p>Weaknesses</p> <ul style="list-style-type: none"> • Costs to implement testing measures must be in-line with the overall economic concept
<p>Opportunities</p> <ul style="list-style-type: none"> • Standard qualification tool also for external companies and institutes • Set a baseline for future norms and standards, peer reviewed publication possible 	<p>Threats</p> <ul style="list-style-type: none"> • High dependency on input from other (sub)-tasks

3.3. Mechanical Process

Competence Group:
Pilot name:

Green Battery
Pilot Project GB-BR-B "Development of a mechanical process for highly material-selective comminution"

Justification for the pilot selection / Background

A used battery system is not necessarily intended for recycling only. The evaluation of a 2nd life is recommended for sustainability at least on system and module level. However, each battery reaches its end-of-life, thus has to be recycled. Currently several recycling plants exist either for pyrometallurgical treatment or for mechanical

processing. For a high recovery rate and reduced energy consumption the mechanical way is required. To ensure safety and efficiency some companies work under cryogenic, inert or vacuum conditions. In this project new concepts using water will be developed and compared with the different known mechanical routes

Pilot key goals and actions

Process routes will be developed for the recycling process section from cell to black mass.

will be developed and tested:

- The aim is pure black mass for a hydro-metallurgical treatment that needs only a minimum of chemicals and energy.

- washing
- skimming & sieving
- centrifugation

Several wet shredding processes will be developed and tested:

Thereafter the combination of both will be optimized.

- Electrohydraulic fragmentation
- Shredding with sprinkling and water bath
- Several following separation processes

Process water treatment will be developed to keep water in the loop.

The process is evaluated and compared to other processes.

Business and funding concepts

Option for the current consortium: National funded project (eg. BMWi)

Integration in the overall Regional Development Concept

Battery development and production is driven by high performance concerning capacity, energy density and lifetime. For a circular economy and a sustainable implementation of renewable energy concepts it is mandatory to generate recyclates for the use in new batteries that can keep the

high standard of state-of-the art batteries. Together with innovative disassembly concepts, recycle analytics and cell production there is an opportunity for the implementation of a recycling plant with the requirement to constantly adapt to new developments in the field batteries.

Supporting expert and industry groups

Research Institutes

- Fraunhofer IWKS

Possible Industry Partners

- Roth international
- BASF
- BHS

SWOT analysis

Strengths <ul style="list-style-type: none">• Reducing chemicals and energy consumption• Geopolitical independence	Weaknesses <ul style="list-style-type: none">• Process water has to be treated
Opportunities <ul style="list-style-type: none">• Closing the loop for battery materials	Threats <ul style="list-style-type: none">• Purity of blackmass could not reach standard for the requirement for efficient low consumption hydrometallurgy

3.4. Hydrometallurgical Recycling

Competence Group:
Pilot name:

Green Battery
Pilot Project GB-BR-C "Methods for the hydrometallurgical recycling of the electrode materials"

Justification for the pilot selection / Background

Most common current battery recycling processes treat the cells pyrometallurgically, which sometimes is combined with an upstream pyrolysis and shredding. The occurring material streams such as black mass need to be treated hydrometallurgically to obtain precursors for the synthesis of new electrode materials. Here, the aim of the entire recycling process is to reach a high recovery rate, low carbon footprint,

sustainable use of critical raw materials (CRM) such as graphite or phosphate and high purity of precursor material. Thus, in the linked pilot projects the development of a mechanical process is focused with the aim to achieve black mass of high purity for the presented pilot project. This is the prerequisite for developing chemical recycling with low consumption of chemicals and energy.

Pilot key goals and actions

Two ways are focused for the recovery of critical materials: leaching and precipitation of precursors for new battery materials and direct recycling.

- Leaching and precipitation: Leaching, filtration of graphite, production of chemical starting compounds
- Direct recycling: lithiation, thermal annealing

Business and funding concepts

Option for the current consortium: National funded project (eg. BMWi)

Integration in the overall Regional Development Concept

Battery development and production is driven by high performance concerning capacity, energy density and lifetime. For a circular economy and a sustainable implementation of renewable energy concepts, it is mandatory to generate recyclates for the use in new batteries that can keep the high standard of state-of-the art batteries.

Together with innovative disassembly and mechanical recycling concepts, recycle analytics and cell production there is an opportunity for the implementation of a recycling plant with the requirement to constantly adapt to new developments in the field batteries.

Supporting expert and industry groups

- Fraunhofer ICT
- Fraunhofer IWKS
- BASF

Next steps

For proper usage, both a facility for battery dismantlement and a facility for the recycling of battery materials are needed.

SWOT analysis

Strengths <ul style="list-style-type: none">• Reducing chemicals and energy consumption• Geopolitical independence	Weaknesses <ul style="list-style-type: none">• Defined materials are required, assuming that the material composition of the batteries is known• High temperature consumption of thermal processes
Opportunities <ul style="list-style-type: none">• Closing the loop for battery materials	Threats <ul style="list-style-type: none">• Risk of not reaching standard quality

3.5. Mechanical Process

Competence Group:

Green Battery

Pilot name:

Pilot Project GB-BR-D "Development of a mechanical process for highly material-selective comminution"

Justification for the pilot selection / Background

A used battery system is not necessarily intended for recycling only. The evaluation of a 2nd life is recommended for sustainability at least on system and module level. However, each battery reaches its end-of-life, thus has to be recycled. Currently several recycling plants exist either for pyrometallurgical treatment or for mechanical

processing. For a high recovery rate and reduced energy consumption the mechanical way is required. To ensure safety and efficiency some companies work under cryogenic, inert or vacuum conditions. In this project new concepts using water will be developed and compared with the different known mechanical routes

Pilot key goals and actions

Process routes will be developed for the recycling process section from cell to black mass.

The aim is pure black mass for a hydrometallurgical treatment that needs only a minimum of chemicals and energy. Several wet shredding processes will be developed and tested:

- Electrohydraulic fragmentation
- Shredding with sprinkling and water bath
-

Several following separation processes will be developed and tested:

- washing
- skimming & sieving
- centrifugation
- Thereafter the combination of both will be optimized.
- Process water treatment will be developed to keep water in the loop.
- The process is evaluated and compared to other processes.

Business and funding concepts

Option for the current consortium: National funded project (eg. BMWi)

Integration in the overall Regional Development Concept

Battery development and production is driven by high performance concerning capacity, energy density and lifetime. For a circular economy and a sustainable implementation of renewable energy concepts it is mandatory to generate recyclates for the use in new batteries that can keep the

high standard of state-of-the art batteries. Together with innovative disassembly concepts, recyclate analytics and cell production there is an opportunity for the implementation of a recycling plant with the requirement to constantly adapt to new developments in the field batteries.

Supporting expert and industry groups

Research Institutes

- Fraunhofer IWKS

Possible Industry Partners

- Roth international
- BASF
- BHS

Next steps The development of a concept and a demonstration line in 3 years.

For proper usage, both a facility for battery dismantlement and a facility for the recycling of battery materials are needed.

SWOT analysis

Strengths <ul style="list-style-type: none">• Reducing chemicals and energy consumption• Geopolitical independence	Weaknesses <ul style="list-style-type: none">• Process water has to be treated
Opportunities <ul style="list-style-type: none">• Closing the loop for battery materials	Threats <ul style="list-style-type: none">• Purity of blackmass could not reach standard for the requirement for efficient low consumption hydrometallurgy

3.6. Hydrometallurgical Recycling

Competence Group:
Pilot name:

Green Battery
Pilot Project GB-BR-E "Methods for the hydrometallurgical recycling of the electrode materials"

Justification for the pilot selection / Background

Most common current battery recycling processes treat the cells pyrometallurgically, which sometimes is combined with an upstream pyrolysis and shredding. The occurring material streams such as black mass need to be treated hydrometallurgically to obtain precursors for the synthesis of new electrode materials. Here, the aim of the entire recycling process is to reach a high recovery rate, low carbon footprint,

sustainable use of critical raw materials (CRM) such as graphite or phosphate and high purity of precursor material. Thus, in the linked pilot projects the development of a mechanical process is focused with the aim to achieve black mass of high purity for the presented pilot project. This is the prerequisite for developing chemical recycling with low consumption of chemicals and energy.

Pilot key goals and actions

Two ways are focused for the recovery of critical materials: leaching and precipitation of precursors for new battery materials and direct recycling.

- Leaching and precipitation: Leaching, filtration of graphite, production of chemical starting compounds
- Direct recycling: lithiation, thermal annealing

Business and funding concepts

Option for the current consortium: National funded project (eg. BMWi)

Integration in the overall Regional Development Concept

Battery development and production is driven by high performance concerning capacity, energy density and lifetime. For a circular economy and a sustainable implementation of renewable energy concepts, it is mandatory to generate recyclates for the use in new batteries that can keep the high standard of state-of-the art batteries.

Together with innovative disassembly and mechanical recycling concepts, recycle analytics and cell production there is an opportunity for the implementation of a recycling plant with the requirement to constantly adapt to new developments in the field batteries.

Supporting expert and industry groups

Research Institutes

- Fraunhofer ICT
- Fraunhofer IWKS

Possible Industry Partners

- BASF

Next steps

For proper usage, both a facility for battery dismantlement and a facility for the recycling of battery materials are needed.

SWOT analysis

Strengths <ul style="list-style-type: none">• Reducing chemicals and energy consumption• Geopolitical independence	Weaknesses <ul style="list-style-type: none">• Defined materials are required, assuming that the material composition of the batteries is known• High temperature consumption of thermal processes
Opportunities <ul style="list-style-type: none">• Closing the loop for battery materials	Threats <ul style="list-style-type: none">• Risk of not reaching standard quality

4. Competence Group Hydrogen

4.1. Subgroup “Large scale industry supply with green hydrogen”

Competence Group:
Pilot name:

Hydrogen
Pilot Project H2-A “Large scale industry supply with green hydrogen”

Justification for the pilot selection / Background

There is an existing large market for green hydrogen, which could deliver strong effects in CO₂ reduction on the large scale with relatively low specific system costs. The Fessenheim region and in particular Chalampé offers unique opportunities for high quality renewable electricity, which allows usage of the production path via the mainstream electrolysis. Additionally the existing hydrogen pipeline may be used as

an effective distribution infrastructure to the lead industry customers. Lacking green hydrogen may be imported via the river Rhine using the powerful harbour infrastructure and extending it with LH₂ storage and bunkering facilities. LH₂ will bridge to other large scale applications not anchored in the industrial area and connected to the pipeline, for instance as a hydrogen supply option for heavy duty transport.

Pilot key goals and actions

- Securing access to hydroelectricity power
- Selecting the optimum lake/water area for building a reference floating PV
- Finalising the land planning for a 200 MW production electrolyser with an initial installation of 40 MW with most direct connection to the existing pipeline
- Installation of the 40 MW electrolyser, producing green hydrogen at costs < 5 €/kg
- Installation of a test bed for new innovative electrolyser cells/stack/ systems for assessing new materials and components under various grid integrated con-

- ditions (operational strategies and concepts for stationary/dynamic operations of electrolyser, electrolyser as flexible load / grid balancing, etc.) and further development of electrolyser technology with regard to performance and costs
- Benchmarking with the 1 MW Grenzach-Whylen pilot plant of Energiedienst
- Further extension to 200 MW and possibly beyond

Business and funding concepts

Estimated investment of 300 m. € for large scale electrolysis (200 MW) and 2 floating PV installations (40 MW).

Industry financed with public support via suitable regulation for eligibility of the grid integration and green electricity supply. Integration in an EU Hydrogen Valley could fund additional costs for the integration in the hydrogen hub. A call for a Hydrogen Valley by the Clean Hydrogen Joint

Undertaking is expected in March 2022 with a maximum EU funding of 25 m.€. Application for an EU OITB for the associated electrolysis test bed.

On the basis of the World Energy Outlook 2020 of the IEA (page 40) and according to studies of H2V it is estimated that based on the investment for operation of the whole system 70-200 jobs might be generated

Integration in the overall Regional Development Concept

Coupling of the electrolysis off-heat into a low heat supply network.

Marketing of the oxygen (e.g., glass, steel industry, hospitals, wastewater treatment, fish farming...)

Supporting expert and industry groups

Research Institutes

- Linde France (as industry gas supplier)
- BASF, Borealis (with huge demand for nylon and ammonia production)
- Siemens (supplier of PEMEC)
- KIT
- UNISTRA
- ISE Fraunhofer

Possible Industry Partners

- EdF/Hynamics (operation of electrolysis)
- EUROGLAS (with potentially huge demand for clean high T heat)
- McPhy, ThyssenKrupp, NEL (supplier of alkaline technology)
- ITM, Cummings, (alternative supplier of PEMEC)

Additionally there is a link to the Battery Competence Group via combining batteries with electrolyzers for optimized operational concepts.

Next steps

A large-scale electrolyser needs to be set-up in the region. The capacity will initially be around 40 MW and should then be expanded further to around 200 MW. An in-

novative electrolyser test-bed can then be installed to test further. A final addition would be the installation of floating PV systems in the region.

SWOT analysis

<p>Strengths</p> <ul style="list-style-type: none"> • Green hydrogen is key for defossilisation of several processes in industry on large scale • Large scales come at low specific costs (however, still above conventional hydrogen) • Electrolysis is a mature technology coming at low investment costs (Alkaline electrolysis TRL= 9) 	<p>Weaknesses</p> <ul style="list-style-type: none"> • No visibility • A Relatively small number of jobs created per investment • No operating partner identified to this date
<p>Opportunities</p> <ul style="list-style-type: none"> • Existing applications and infrastructures (e.g. pipeline) of “grey” hydrogen may be easily converted to “green” • Large scale effects in CO₂ reductions at relatively low specific costs • Industry scaled hydrogen production might supply other more distributed use cases like transport with hydrogen at a highly attractive price level • Electrolysis might use existing infrastructure • Industry will generate new highly profiled jobs • Synergies with the other actions • EU-wide political willingness to develop renewable H₂ production 	<p>Threats</p> <ul style="list-style-type: none"> • Threats • Neither suitable regulation, nor a business case for EDF for accessing hydroelectric power • Required additionality and locality might impede the use of hydroelectric power • Insufficient opportunities for additional floating PV • General run on electrolyser technology might delay the purchase, delivery and installation • Production costs still higher than conventional hydrogen • Lack of regulations of the green H₂ industry considering its novelty

4.2. Subgroup “Virtual Pipeline”

Competence Group:
Pilot name:

Hydrogen
Pilot Project H2-B “Virtual Pipeline”

Justification for the pilot selection / Background

Import infrastructure for green hydrogen needed as local production of green H₂ might be limited. Real pipelines are long-term projects binding huge investments, and are not very flexible. Besides the plans

for connecting the Fessenheim region with the European hydrogen backbone transport grid foresee connection only in ~ 2040

Pilot key goals and actions

Demonstrate functionality of „Virtual Pipeline“ consisting of:

Two Rhine harbour installations (one at Ottmarsheim and one at Karlsruhe) with LH₂ bunkering and large-scale storage.

- Low water capable, FC hybrid electric transport vessel for ISO containers in operation.
- Build „Green liquefier“ (highly efficient, green H₂ and electricity) at Fessenheim (1 t/d capacity).

Business and funding concepts

Estimated investments of 140 m.€ in total (100 m.€ liquefier, 30 m.€ storage+bunkering, 10 m.€ container vessel FC refit)

- Apply for public support/funding (Hydrogen Valley call in 02/2022)
- Involve interested Industry: Liebherr, MTU, Air Liquide, Miro, BASF, Stolt Tankers, DST...
- Close connection to planned projects, in particular BW model region,...
- Specific link to Fessenheim: existing harbour infrastructure, potential large

scale electrification, bridging to Switzerland ...

- Participation in H2Global

On the basis of the World Energy Outlook 2020 of the IEA (page 40) it is estimated that based on the investment for operation of the whole system up to 500 jobs might be generated.

Integration in the overall Regional Development Concept

LH₂ in particular allows multiple coupling with superconducted electricity (LI-QHYSMES, icefuel concepts) and cooling demand. It provides a basis for trading

green energy on longer distance, but could also serve as an economic option for seasonal storage of green energy

Supporting expert and industry groups

Research Institutes

- KIT
- UNISTRA
- ISE Fraunhofer
- University of Applied Science Karlsruhe

Possible Industry Partners

- Air Liquide for bunkering system
- Linde France for liquefier
- CryoStar as Mulhouse based supplier for cryo-equipment
- MTU for green harbour infrastructure and FC drivetrain of container vessel
- BASF as lead customer for additionally imported hydrogen

Next steps

Steps should be taken to build an enhanced pipeline system for storage and transport of hydrogen. A container based bunkering facility will aid in this endeavor.

An FC driven container vessel will then be employed in the region. A hydrogen liquefier and corresponding LH₂ storage are necessary additions.

SWOT analysis

<p>Strengths</p> <ul style="list-style-type: none">• Increase scale and improve economy by import capability• Integrating Fessenheim in a larger community by using existing infrastructures and the unique location D/F/CH at the river Rhine	<p>Weaknesses</p> <ul style="list-style-type: none">• LH₂ technologies are expensive equipment that requires important investments
<p>Opportunities</p> <ul style="list-style-type: none">• Establishing Fessenheim region as central trading point/dispatching center for green energy via LH₂ might serve as a template for other regions	<p>Threats</p> <ul style="list-style-type: none">• No/limited funding available• Liquid is not seen as attractive option

4.3. Subgroup “Heavy Duty Transport”

Competence Group:

Hydrogen

Pilot name:

Pilot Project H2-C “Heavy Duty Transport”

Justification for the pilot selection / Background

The CO₂ reduction required by European regulation will induce the introduction of hydrogen as a fuel for heavy duty transport especially for long distance and energy intensive transport services. The important infrastructural location of the southern Fessenheim region, i.e. Ottmarsheim, connecting Northern Switzerland, Grand-Est

of France with the South-West of Germany has led many transport companies to operate branches in this area. Tax law specifics in Switzerland have already allowed an industry-led consortium to commercially operate a fleet of Hyundai fuel cell trucks. The Fessenheim region could be developed as a strategic extension of this project.

Pilot key goals and actions

Proper land and supply planning for large State-of-the-Art fueling station (initially 1 t/day finally 5 t/ day) in the area Ottmarsheim

Set-up of the State-of-the-Art fueling station for heavy duty trucks

Design and conduct and initially predominant research and testing program before the actual operation of the station for fleet fueling services

- Establishment of the service company selling H2 based clean transport
- Negotiating best conditions (taxation, hydrogen pricing,...) and selling of packages to customers
- Actual commercial operation of the system, consisting of station and fleet
- Plan for end-of-life

Business and funding concepts

Estimated investments of 10 m. € in total (7 m. € for state-of-the-art LH2 based heavy duty fueling station with research interfaces; 3 m. € for 20 HD trucks)

On the German side public programs currently cover 80% of the additional costs for trucks and fueling stations compared to conventional solutions (invest). The operational costs might be close to current costs with conventional (even with costs for hydrogen > 5 €/kg fueled).

ADEME call for projects on the French side: up to 55% of the additional costs for trucks and fueling stations compared to

conventional solutions. To get the funds, at least 50% of the off takers must be identified.

Copying the Swiss business model with a service entity offering clean transport on a (ton*km) basis to the customers, consisting of forwarding/shipping companies and other major industry customers with high transport demand seems to be the most promising approach.

On the basis of the World Energy Outlook 2020 of the IEA (page 40) it is estimated that for the fleet and fueling station operation 40 - 50 jobs might be generated.

Integration in the overall Regional Development Concept

The heavy duty fueling station might be combined with fast charging points for battery based heavy-duty distribution trucks or battery based buses.

The liquid hydrogen stored might cool su-

perconducting charging points or other high power systems.

It should be openly accessible to demonstrate safety and to “share” the technology with the public.

*Supporting expert
and industry groups*

Research Institutes

- KIT (ITES, ITAS) (Aufzählungszeichen fehlt)
- Troyes' Institute of Services and Industries
- of the Future
- University Hohenheim
- FhG- ICT Pfinztal
- FhG-ISE (Karlsruhe)

Possible Industry Partners

- Fuel supplier: Linde France, Air Liquide
- Refueling station operator: Shell, Total
- CryoStar
- Truck suppliers: Hyundai, Daimler Trucks
- Logistics: Grieshaber, Schenker and JCL Logistics

Next steps

A heavy duty refueling station is needed as a prerequisite for other undertakings. Interfaces for refueling protocols, metering, etc. will then have to be researched and

developped. A fleet of heavy-duty hydrogen vehicles can then be deployed on a wider scale.

SWOT analysis

<p>Strengths</p> <ul style="list-style-type: none"> • Close proximity to Germany where a strong HRS network already exists (about 100 HRS) • High heavy duty traffic: up to 13.000 trucks per day (see p.36 in the SudAlsace study) • International highway, intersection of the A5 (DE) A35 (FR) and A36 (FR) at Ottmarsheim • Large scale with huge potential impact on CO₂ footprint in heavy duty transport • Assuring the future of transport companies with a strategic function in this special location • Realisation of CO₂ free multi-modal transport 	<p>Weaknesses</p> <ul style="list-style-type: none"> • No commitment of the nearby PSA site • Little to no interface with the public, as the concerned trucks are mainly operated on highways • Lack of data concerning the daily refueling of trucks in the Ottmarsheim region
<p>Opportunities</p> <ul style="list-style-type: none"> • Rise of the costs for oil, reduction of tolls for zero emission vehicles • Rise of the carbon tax by more than 100% in France between 2018 and 2030 • Hydrogen more profitable than Diesel at this time • Using the hydrogen fueling station also for a bus fleet in Mulhouse • Establishing the stations as a test bed for future, innovative fueling concepts • Expected ban of new diesel vehicles by 2040 • Expected subsidies for H2 vehicles adoption 	<p>Threats</p> <ul style="list-style-type: none"> • Important costs for transport companies which might choose to not invest in H2 trucks • Fueling stations might become a stranded asset with an unresolved "chicken and egg" problem (as happened for the > 100 hydrogen stations in Germany with too few hydrogen fuel cell cars) • Swiss concept might fail because of different regulation, taxation etc.

4.4. Subgroup “Distributed production and use in agriculture”

Competence Group:

Pilot name:

Hydrogen

Pilot Project H2-D “Distributed production and application of green hydrogen in agriculture”

Justification for the pilot selection / Background

The overall potentials of agriculture and forestry as one backbone of a hydrogen-based society and economy are complex, significant, but often completely underestimated. Because cities could not harvest renewable energy in sufficient amounts, it is up to the landscape to pervade the increase of renewable energy. To integrate agriculture and forestry as one major player in a win-win approach could lead Europe into a promising future. With well thought-out approaches, it is possible to demonstrate in the region around Fessenheim, both technical utilisation and application possibilities of hydrogen technology as well as synergy effects for demonstration. Valuable pathways need a concentration on essential core elements and objectives:

1. The use and benefit of biomass for the production of hydrogen (e.g., methane-cracking by plasmalysis)
2. The use of hydrogen in agriculture (e.g., combustion engine and fuel cells, H₂ and CH₄)
3. Synergetic effects and harmony of the use of renewable energy on agricultural land (e.g., transparent solar panels)

4. Decentralised character in future and increasing independence (regional approach)
5. Transfer of outcomes to similar areas

The emission of methane (e.g., through livestock) is an additional aspect to be addressed. Methane as a climate-damaging gas used to produce hydrogen. Simultaneous production of carbon-based materials that either can be used on agricultural soils (closing the carbon cycle) or carbon based materials for technical products. The potential is high for both, deposition of carbon and synthesising of specific carbon based materials (as basic materials) for further processing.

In addition, results achieved (e.g., technological and engineering solutions) transferable to other types of similar areas, through the direct use of methane produced, e.g., by wastewater treatment plants, landfills. Specifically novel technological approaches in producing hydrogen from bio-methane for instance by plasma-driven technology (methane-cracking) can build the basis of decentralised hydrogen production in midterm.

Pilot key goals and actions

- Investigating the potentials for production of hydrogen by methane-cracking by use of novel technology to be developed, plasmalysis and optional pyrolysis (low TRL) operated by use of renewable energy
- Selecting potentials for hydrogen driven applications on farms and business environment (e.g., combustion engines tractors and towing vehicles, mews etc.)
- Investigating synergies between market gardening and use of transparent PV installations (protections exhaustive solar radiation, volley, dry out of soils, etc.)
- Installation of a test PV bed for new innovative technology in hydrogen production out of bio-methane
- Option to operate with bio-methane in HT Fuel Cells
- Benchmarking pilot plant of Energy Service on local areas
- Further extension to MW scale and possibly beyond

Business and funding concepts

The interaction between agriculture, forestry, rural communities, energy suppliers and renewable energy and hydrogen technology based industry must be introduced to funding organisations more appropriate and promising. Some funding organizations have open opportunities to cover the aspects. Potential interest for those kinds of projects (demonstration projects):

- European council (EU)
- Agence Nationale de Recherche (FR)
- Grand Est Region (FR)
- Baden Württemberg Land (DE)
- BMU (DE)
- BMBF/BMWI (DE)

Integration in the overall Regional Development Concept

This project will contribute to the decarbonisation of agriculture, harvesting renewable energy by PV, producing hydrogen by bio-methane, deposition of carbon and introducing hydrogen technology in rural areas. This will also lead to more visibility and public acceptance.

The market is still not existing, but technology developed and ready to get installed and tested (low TLR level)

Specifically, the use of carbon based materials for deposition on agricultural soils and/or forestry as well as usage of basic materials for technical products could lead to breakthrough application.

- Contribute to the ongoing effort of creating a European industry and supply chain of hydrogen applications
- Use of carbon to support the circular economy (decarbonisation)
- Increase the use of renewable energy and hydrogen production
- Synergies between agricultures and energy harvesting

Strengthen the interconnection of renewable energy and agriculture (farming and forestry) reach a European (maybe) worldwide impact

Supporting expert and industry groups

Research Institutes

- KIT (ITES, ITAS)
- Troyes' Institute of Services and Industries of the Future
- University Hohenheim
- FhG- ICT Pfinztal
- FhG-ISE (Karlsruhe)

Possible Industry Partners

- Farmers and Forests House
- Energy supplier
- FCH-Industry
- Industry using carbon based materials
- PV-Industry (production of solar panels)
- Rural communities

Next steps

The construction of a prototype biogas-based production plant is the first step, followed by the installation of fuelling stations for agricultural machines. With both

of these in place, a deployment of a fleet of hydrogen driven agricultural machines is possible.

SWOT analysis

<p>Strengths</p> <ul style="list-style-type: none"> • Green hydrogen as key for decarbonization of agriculture • Deposition of carbon on soils (potentially with impact) • Prevention of uncontrolled emission of methane • Decentralized production of hydrogen out of bio-methane • New market for applications (FCH technologies) • Increasing independence of local communities • Synergies between agriculture and energy harvesting (renewable energy) 	<p>Weaknesses</p> <ul style="list-style-type: none"> • Low TLR levels (e.g., plasmalysis methane-cracking and potential use of pyrolysis) • Less knowledge of depositing massive carbon based materials on agricultural soils • Less visibility • A Relatively small number of jobs created per investment • Low acceptance from the general public and farmers, thus need to communicate on the potential gains
<p>Opportunities</p> <ul style="list-style-type: none"> • Combustion engines based on hydrogen for tractors and towing vehicles • Capacities for storage systems (hydrogen and methane) • Hydrogen through methane cracking by means of pyrolysis or plasmalysis • Prevention of market gardening • Large scale effects at relatively low specific costs • Industry scaled hydrogen production might enable other more distributed use cases • Synergies with the other actions • Deposition of carbon based materials and potential positive effects 	<p>Threats</p> <ul style="list-style-type: none"> • Less knowledge about effects of depositing carbon based materials on agricultural soils • No business case for Energy suppliers • Technology for methane-cracking on low TLR • No acceptance of approach or technology • Costs won't come down compared to conventional hydrogen

5. Competence Group Smart Grids

5.1. Twin Quarter Pilot

Competence Group:
Pilot name:

Smart Grids
Pilot Project SG-A "Twin quarters Mulhouse - Karlsruhe"

Justification for the pilot selection / Background

In the city of Mulhouse there are two possibilities of integration of smart grids. The first one in the Fonderie quarter which includes industrialists and the second one in the DMC quarter with a mix of uses in development.

the city; this project is in collaboration with the KIT and Seven2one.

For the Fonderie quarter. The city of Mulhouse is planning to set up businesses and the idea is to create a sustainable quarter between already existing smart grid quarters in Karlsruhe and Mulhouse to create an exchange of expertise between both.

In Karlsruhe, such a project is ongoing in the East quarter for the energy transition in

Pilot key goals and actions

Goals

- Reduce energy consumption, efficiency
- Integrating renewable energy and storage
- Couple electricity, heat and cold
- Develop e-mobility
- Analyze the uses, creation of learning databases
- Develop respective business models
- Create an exportable model (ex: EcoRhena)
- Labellisation ISO 50 001, Energy Management
- Both become "climate cities"

Actions

- Create a consortium for Mulhouse (already existing at Karlsruhe)
- Define common objectives (sharing of competences and ideas)
- Develop acceptability and economical model
- Join grids simulation (ex: RDTS / OPAL-RT)

Business and funding concepts

Funding organisations to be solicited:

- ADEME (FR)
- BPI (FR)
- Grand Est Region (FR)

Integration in the overall Regional Development Concept

The installation of smart grids in a district with industrial potential will make it possible

to reduce electricity consumption thanks to the analysis of uses.

Supporting expert and company groups

Research Institutes

- University of Mulhouse
- University of Strasbourg
- University of Freiburg
- Fraunhofer ISE
- Karlsruhe Institute for Technology

Possible Industry Partners

- Seven2one (Smart East quarter in Karlsruhe)

Next steps

In a first step, local authorities (m2A, ville de Mulhouse) were contacted. On the German side, this has taken place already as well (Karlsruhe Smart East). The Mulhouse delegation visited Karlsruhe in Janu-

ary. A French-German consortium then needs to be established. Finally, applications for funding to calls have to be submitted.

SWOT analysis

Strengths <ul style="list-style-type: none">• Experience and knowledge in Energy Management• Several contacts with local companies	Weaknesses <ul style="list-style-type: none">• Data collection (ex: smart meter)
Opportunities <ul style="list-style-type: none">• Data collection (ex: smart meter)	Threats <ul style="list-style-type: none">• Data collection (ex: smart meter)• no investment by the quartier

5.2. European Grid Pilot

Competence Group: **Smart Grids**
Pilot name: **Pilot Project SG-B "European Grid Development"**

Justification for the pilot selection / Background

Solving the problem of stability of electric power distribution including the connection of the German and French networks with electric interconnections development: high level (some GW) middle level (less than 1 GW)

Tackle the issue of energy mix integration on the grid at an European level

Pilot key goals and actions

Goals

- Robust stability of the grid, keep the frequency close to 50Hz
- Optimize the energy mix towards decarbonisation
- Integrate local grids with transnational grid
- Enhance the commercial transaction balance

Actions

- Collaboration between NetzeBW/ TransNetBW and RTE (already existing thanks to the Fraunhofer ISE)
- Define the scientific open questions
- Join grids simulation (ex: RTDS / OPAL-RT)

Business and funding concepts

Funding organisations to be solicited:

- The European Structural and Investment Funds (ESIF)

Integration in the overall renewable energy and circular economy concept for the region towards CO₂ neutrality

Integrate a stability of the German and French network

Supporting expert and industry groups

Research Institutes

- University of Mulhouse
- University of Strasbourg
- University of Freiburg
- Fraunhofer ISE
- Karlsruhe Institute for Technology

Possible Industry Partners

- RTE (FR)
- NetzeBW (DE)
- TransNetBW (DE)
- EDF (FR)

Next steps

A meeting with NetzeBW, TransNetBW, RTE and EDF has to be organised, because of the closure of the Fessenheim plant.

SWOT analysis

<p>Strengths</p> <ul style="list-style-type: none">• Experience and knowledge in Energy Management• Several contacts with local companies• existing cross border lines	<p>Weaknesses</p> <ul style="list-style-type: none">• Data collection (ex: smart meter)• political will
<p>Opportunities</p> <ul style="list-style-type: none">• Data collection (ex: smart meter)• a more integrated energy market• better grid stabilization• better electricity management	<p>Threats</p> <ul style="list-style-type: none">• regulative barriers• investments into the grid

5.3. EV Charging Grid Pilot

Competence Group:
Pilot name:

Smart Grids
Pilot Projects SG-C "Electric vehicles charging stations grid"

Justification for the pilot selection / Background

Management of the location of electrical charging stations, charging strategy, development of charging points numbers in cities.

Also, maybe Black Forest could be a prototype region because of advantage of electromobility due to recuperation when driving down.

One concrete example in Mulhouse Agglomération (m2A) with 150 new points of electric charging stations.

Pilot key goals and actions

Goals

- Optimize the charging station network of a district, a city or a road network
- Reduce power peaks with battery (2nd-life battery)
- Optimize the coupling between the charging load network and the distribution network
- Develop a profile and a usage model
- Standardisation of charging network

Actions

- Create a consortium (ex: "Daimler", "Stellantis", Enedis, EDF...)
- Application of metaheuristics & stochastic search algorithms
- Define topology
- Develop simulations

Business and funding concepts

Funding organisations to be solicited:

- ADEME (FR)
- Grand-Est Region (FR)

Integration in the overall renewable energy and circular economy concept for the region towards CO₂ neutrality

Reduce the impact of carbon emissions through the installation of electric charging stations for vehicles

Supporting expert and company groups

Research Institutes

- University of Mulhouse
- University of Strasbourg
- University of Freiburg
- Fraunhofer ISE
- Karlsruhe Institute for Technology

Possible Industry Partners

- Daimler (DE)
- Izivia (FR)
- EDF (FR)
- Enedis (FR)
- INPUT 2.0
- LAMA

Next steps Contact to EDF (and Izivia) and m2A has been established. Next, it is necessary to apply to calls for projects by m2A.

SWOT analysis

Strengths <ul style="list-style-type: none">• Experience and knowledge in Energy Management• Several contacts with local companies• electricity charging stations are planned	Weaknesses <ul style="list-style-type: none">• no clear investment commitments• industry not yet involved
Opportunities <ul style="list-style-type: none">• testbed installations	Threats <ul style="list-style-type: none">• data protection• no good business model



ZUSAMMENFASSENDE BERICHT

Machbarkeitsstudie Innovationsregion Fessenheim
2021 – 2022

Herausgegeben von Barbara Koch

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Die Grundidee der Machbarkeitsstudie ist das Identifizieren durchführbarer Transformationspfade für die Energiewirtschaft, verbunden mit einer nachhaltigen zukunftsorientierten Industrie, der Einbindung einschlägiger Studien, Wissenschaftspartner und Stakeholder aus der Gesellschaft, der Industrie und Wirtschaft.

Barbara Koch

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01. Einführung

Die Notwendigkeit einer nachhaltigen Entwicklung hat den umweltpolitischen Diskurs im 21. Jahrhundert dominiert und ihn zu einem übergreifenden politischen Paradigma gemacht (Komiya; Takeuchi, 2006; Spangenberg, 2011). Im Laufe der Zeit stand die Rolle einschneidender und systemischer Innovationen bei der Erreichung der Ziele der nachhaltigen Entwicklung im Vordergrund (Boons et al., 2013).

Die Machbarkeitsstudie "Innovationsregion Fessenheim" geht von einem ähnlichen Ethos der nachhaltigen Innovationen aus. Im Mittelpunkt der Studie steht die Entwicklung einer Pilot-Innovationsregion auf der Basis innovativer, neuer Technologien zur Erreichung von Emissionsneutralität und Nachhaltigkeit im Energiesystem sowie zur Förderung der lokalen Wertschöpfung und Arbeitsplatzschaffung. Auf der Grundlage einer bilateralen Verständigung soll die Machbarkeitsstudie ein Modell für die grenzüberschreitende europäische Regionalentwicklung ausarbeiten. Die Studie schlägt Ideen für Demonstrationsprojekte - in den Bereichen "Grüne Batterien", "Grüner Wasserstoff" und "Intelligente Stromnetze" - vor und beleuchtet die Verflechtungen und wechselseitigen Vorteile ihrer möglichen Umsetzung (siehe Abbildung 1).

Mit einem interdisziplinären und praxisorientierten Ansatz zielt die Machbarkeitsstudie darauf ab, gemeinsam mit Partnern und Akteuren aus Wissenschaft, Wirtschaft, Politik, öffentlicher Verwaltung und Zivilgesellschaft die Defossilisierung des Energiesystems und damit der Wirtschaft in der Region voranzutreiben. Um eine übergreifende Koalition zu bilden, nutzt das Projekt die im Oberrheincluster für Nachhaltigkeitsforschung (URCforSR) vorhandenen Kompetenzen ebenso wie die einzelner Forschungsinstitute und Hochschulverbände, wie Eucor - The European Campus und TriRhenaTech. Der Hauptschwerpunkt und die Stärke der Studie liegen darin, das breite wissenschaftliche Wissen und Fachwissen im Oberrheintal mit dem praktischen Wissen von Industrie und gesellschaftlichen Akteuren zusammenzubringen. Als Ergebnis früherer trinationaler Studien (RES-TMO, Smart Meter, SumoRhine) und der „Projet de Territoire“-Studie wurden vier wichtige Elemente für die Entwicklung der Innovationsregion ermittelt:

1. Die Demonstration neuer technologischer Konzepte im Zusammenhang mit nachhaltiger Energieinnovation durch regionale Living Labs, die den Bürgern in Zukunft greifbare Ergebnisse liefern können.
2. Die Verbindung zwischen dem in der Region vorhandenen wissenschaftlichen Know-how und den industriellen Investitionen durch Transformations- und Innovationszentren.
3. Die Entwicklung von Konzepten zur Integration der Bereiche Ausbildung, Weiterbildung und Lehre zur weiteren Stärkung der Modellregion.

4. Die Initiierung eines Diskurses mit den verschiedenen Gemeinden in der Region über die Vision des Projekts und der konkreten Innovationspiloten sowie Berücksichtigung ihrer Beiträge.

Zusammen bilden die oben genannten Elemente die Säulen für die Entwicklung einer grenzüberschreitenden Innovationsregion und tragen zur Hauptidee der Machbarkeitsstudie bei.

Leitgedanke der Machbarkeitsstudie ist es, unter Einbeziehung relevanter Studien, Wissenschaftspartner und Stakeholder aus Gesellschaft und Wirtschaft, tragfähige Transformationsfelder für die Innovationsregion zu identifizieren, die unter Berücksichtigung des gesamten regionalen Primärenergieverbrauchs eine Transformation hin zu einem zukunftsorientierten Industrie- und Energiemarkt einleiten. Konkret ist die Vision der Studie das Errichten:

- Einer grenzüberschreitenden europäischen Innovationsregion durch die Vernetzung regionaler Akteure aus Wissenschaft, Wirtschaft und Gesellschaft
- Eines europäischen Vorbilds (Living Lab) als Beispiel für einen gesellschaftlichen und industriellen Wandel hin zur Nachhaltigkeit

Zu diesem Zweck wurden nach einer Analyse der regionalen Vorzüge des Oberrheins und der Innovationsregion Fessenheim Entwicklungsfelder identifiziert, die den Anforderungen der im „Projet de Territoire“ hervorgehobenen politischen Forderungen entsprechen. Die im „Projet de Territoire“ beschriebenen politischen Ziele sind eingebettet in die europäischen, nationalen und regionalen Ziele zur Erreichung von Nachhaltigkeit und Klimaneutralität.

Neben den Transformationszielen in Richtung Nachhaltigkeit und Klimaneutralität hat das „Projet de Territoire“ postuliert, dass mit der Schaffung von Technologie-Innovationszentren in der Region folgende Punkte Berücksichtigung finden sollen:

- Zukunftsorientierte Beschäftigung
- Innovationsindustrien
- Grenzüberschreitende Bildung und Ausbildung
- Beteiligung der Bürger

Indem die postulierten Ziele des „Projet de Territoire“ mit den regionalen Vorzügen des Oberrheins und der Innovationsregion Fessenheim verknüpft werden, basieren die Ideen für die Entwicklung von Pilotprojekten als Best-Practice-Beispiele auf vier Kompetenzgruppen. Drei Kompetenzgruppen werden als technologische Innovationshubs eingestuft:

1. Innovationshub für grüne Batterien und Kreislaufwirtschaft von Batterien
2. Innovationshub für Grünen Wasserstoff
3. Innovationshub für intelligente Stromnetze

Darüber hinaus untersucht die vierte Kompetenzgruppe "territoriale Rahmenbedingungen" die ökologischen, gesellschaftlichen, regulativen und wirtschaftlichen Rahmenbedingungen für die Umsetzung der Innovationshubs aus den drei Kompetenzgruppen (Abbildung 1).

CO₂-neutral energy and transportation concept

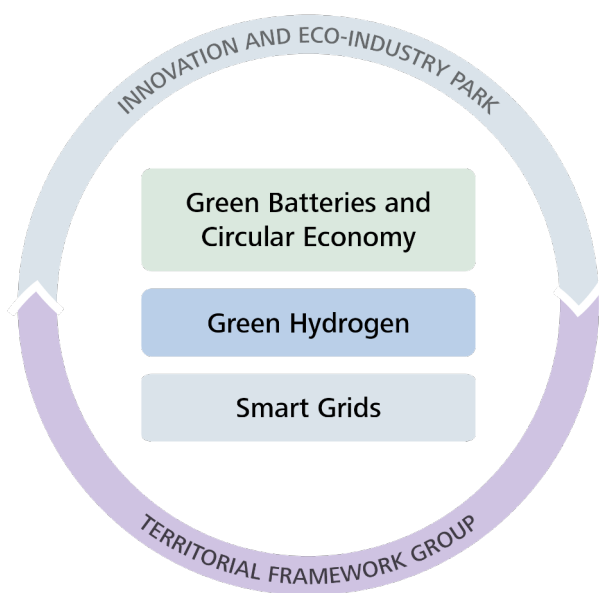


Abbildung 1. Innovationsfelder für die Entwicklung von Best-Practice-Beispielen eingebettet in territoriale Rahmenbedingungen und angesiedelt in Innovations- und Öko-Industrieparks.

Ein weiterer zentraler Gedanke ist, dass die ausgewählten technologischen Innovationshubs miteinander verbunden und korreliert sind, so dass diese für eine erfolgreiche und nachhaltige regionale Transformation gleichzeitig ausgeführt werden müssen. Genauer gesagt ist die Verbindung zwischen Batterien und Grünem Wasserstoff von großer Bedeutung für die gesamte regionale Transformation, da sie sich in Bezug auf die Implementierung eines Speichersystems für volatile erneuerbare Energien, die Stabilisierung des Netzes und den Beitrag zu Verkehrs- und Industrieprozessen ergänzen. Die unterschiedliche Zeitlichkeit bei der Energiespeicherung und die verschiedenen Transportmöglichkeiten bieten komplementäre Sicherheit und Flexibilität im Energiesystem (Specht et al., 2004). Was beispielsweise industrielle Anwendungen betrifft, so sind Batterien in ihrer Anwendung zur Energieversorgung flexibel, aber nicht so sehr für energieintensive Prozesse geeignet, während Grüner Wasserstoff in energieintensiven industriellen Prozessen besonders effizient und energiesparend eingesetzt werden kann. Im Verkehrsbereich hingegen, können Batterien im Personenverkehr gut eingesetzt werden, während Grüner Wasserstoff im Schwerlastverkehr mit Schiffen, Zügen oder Schwertransport auf der Straße, den Batterien überlegen sein könnte. Darüber hinaus ist die Anpassung des Stromnetzes an die erneuerbaren Energien notwendig, um den Anteil der erneuerbaren Energiequellen zu erhöhen. Die innovativen Anwendungen, die in den Innovationszentren für Batterien und Grünem Wasserstoff beschrieben werden, können dies unterstützen, da sie beide zu einer ausreichenden und zeitnahen Stromversorgung durch ihre Speichermöglichkeiten beitragen können.

Vor diesem Hintergrund wird in den folgenden Kapiteln auf die lokalen Vorzüge der Region Fessenheim eingegangen und ein Überblick über die Themen, Forschungsarbeiten und Empfehlungen der einzelnen Kompetenzgruppen gegeben, um die vollständige Umsetzung der vorgeschlagenen und sich ergänzenden Pilotprojekte zu unterstützen.

02. Regionale und lokale Stärken für die Innovationsregion Fessenheim

Wie in der Einleitung bereits erwähnt, basieren die Themen der Kompetenzgruppen auf den politischen Zielen und regionalen Vorzügen der Innovationsregion Fessenheim. In diesem Kapitel wird ein Überblick über die regionalen Vorzüge gegeben.

Die Innovationsregion Fessenheim ist in das Oberrheingebiet (Mandatsgebiet der Oberrheinkonferenz), einer geographisch vielfältigen Region im Dreiländereck Frankreich, Schweiz und Deutschland eingebettet. Der Rhein ist der Hauptverkehrsweg der Region und bildet ihre natürliche Grenze. Die Region ist geprägt durch das Rheintal, das im Westen von den Vogesen und im Osten vom Schwarzwald umschlossen wird. Am südlichen Rand befinden sich die Ausläufer des Juras in der Schweiz. Die tri-nationale Metropolregion wird von mehr als sechs Millionen Menschen bewohnt (Jung et al., 2012) und verfügt über eine starke Wirtschaftsleistung (272 Mrd. BIP/Jahr) (Regierungspräsidium Freiburg, n.d.). Direkt an den Raum Fessenheim schließt eine gut vernetzte Verkehrsinfrastruktur an, die drei europäische Verkehrskorridore, die gut ausgebauten europäischen Gaspipelines und das europäische Hochspannungsnetz umfasst (EC DG Mobility and Transport access 27.02.2022).

Die Oberrheinregion eignet sich aus mehreren Gründen als Innovationsdrehscheibe in den oben genannten Bereichen. In erster Linie verfügt die Region über ein hohes wirtschaftliches Potenzial, das sich in einem BIP von 272 Mrd. EUR/Jahr niederschlägt – mehr als das von Finnland und Irland zusammen (Regierungspräsidium Freiburg, o.J.). Darüber hinaus fördert die vorhandene industrielle Infrastruktur in der Region die Entwicklung kleiner und mittlerer Unternehmen (Interreg Oberrhein, 2019). Da die grenzüberschreitenden industriellen Aktivitäten stark ausgeprägt sind, können gemeinsame grenzüberschreitende Investitionsprojekte einen großen Mehrwert schaffen. Eine Studie der Europäischen Kommission schätzt, dass das Wachstumspotenzial in den Grenzregionen eine Wachstumsrate von 485 Milliarden Euro erreichen kann, wenn sie mit einem starken Abbau der rechtlichen und administrativen Barrieren einhergeht (Europäische Kommission, 2017), die für einen Verlust von 3% des europäischen BIP verantwortlich sind (Europäische Kommission, 2017). Passenderweise liegt der Schwerpunkt dieser Machbarkeitsstudie auf barrierefreien Innovationshubs. Im Jahr 2018 gab es in der Oberrheinregion rund 3,2 Millionen Arbeitsplätze. 97.000 Arbeitnehmer pendelten in die Nachbarländer, davon 61 % aus dem Elsass und 38 % aus Baden-Baden. Die Zahl der Grenzpendler ist im Vergleich zu 2008 um 12 % gestiegen (Oberrheinkonferenz, 2020).

Laut der Studie über grenzüberschreitende Regionen des Berichts 2017 der Europäischen Kommission (EK) kann die Zahl der Beschäftigten durch gemeinsame Investitionen gesteigert werden. Tatsächlich überschreiten nur 2 % der

EU-Bürgerinnen und -Bürger die nationalen Grenzen innerhalb der EU, aber 66 % der Bürgerinnen und Bürger entlang der Grenzregionen überschreiten regelmäßig die nationalen Grenzen innerhalb ihrer Region (Europäische Kommission, 2017). Das Potenzial für die Entwicklung neuer Arbeitsplätze in europäischen Grenzregionen wurde in dem in 2017 veröffentlichten Bericht der Europäischen Kommission auf acht Millionen geschätzt. Daher sind die Grenzregionen wichtig für die komplementäre, horizontale europäische Integration.

Die Stärken der Oberrheinregion, die zur nachhaltigen Transformation und zum Wachstum der Region sowie zum Mehrwert für die Gesellschaft und die Wirtschaft beitragen können, sind die folgenden:

Erstens: Die chemische und pharmazeutische Industrie ist für die Schaffung von Arbeitsplätzen und die Wertschöpfung von großer Bedeutung. Um global wettbewerbsfähig zu bleiben, ist es jedoch dringend erforderlich, diese regionale Industrie in eine energieeffizientere Industrie mit weniger CO₂-Emissionen umzuwandeln. Zu diesem Zweck muss der Transfer innovativer Technologien an Unternehmen auf der Grundlage von Best-Practice-Beispielen verstärkt werden.

Zweitens: Der Oberrhein darf sich vielversprechende Investitionen im Verkehrssektor, im Energiesektor oder bei der Schaffung einer Kreislaufwirtschaft nicht entgehen lassen. Was beispielsweise den Verkehrssektor betrifft, so hat die Region ein großes Verkehrs- und Handelsvolumen; daher könnten Emissionsenkungen im Verkehrssektor eine große Wirkung haben und zur Klimaneutralität beitragen. Darüber hinaus ist die Oberrheinregion eng mit der Automobilindustrie verbunden und verfügt über die entsprechenden Technologien und Innovationen, die die Umstellung des Verkehrssektors auf Klimaneutralität unterstützen (einschließlich der Komponenten für die Automobilherstellung). Mit den neuesten klimaneutralen Trends Schritt zu halten, ist auch für die Schaffung von zukunftsorientierten Arbeitsplätzen in der Region von großer Bedeutung.

Drittens: Die Oberrheinregion hat eine zentrale Lage in Europa und verfügt über zahlreiche zuverlässige Verbindungen und Routen, die einen multimodalen und effizienten Warentransport ermöglichen. Die regionale Verkehrsinfrastruktur umfasst: die bestehenden Verkehrskorridore Rhein-Alpen, Atlantik und Rhein-Donau, die an die führenden europäischen Seehäfen Rotterdam - Genua - Marseille (Rhone-Schifffahrtroute) und die weiter unten in Richtung Schwarzes Meer gelegenen Donauhäfen anbinden. Des Weiteren bestehen entlang der Verkehrskorridore wichtige Eisenbahn- und Autobahninfrastrukturen, die auch als Verbindung zwischen den Schifffahrtsrouten dienen. Die wichtigsten Verkehrsverbindungen am Oberrhein sind die Nord-Süd-Verbindungen, die entsprechend

des Berichtes der Hafenverwaltung in Kehl (Hafenverwaltung Kehl, 2015) hervorragende Bedingungen für das Be- und Entladen der Häfen bieten. Außerdem befinden sich wichtige europäische Gaspipelines und Stromleitungen in dem Gebiet. Diese Anlagen sind vorhanden und können bei Bedarf für den Transport von grünem Strom oder Grünem Wasserstoff in Zukunft von Norden nach Süden oder bezüglich Strom über das europäische Hochspannungsnetz in alle Richtungen angepasst werden.

Viertens: In der Region gibt es eine hohe Konzentration von Forschungs- und Bildungseinrichtungen, darunter weltweit anerkannte Institute in den Bereichen Energietechnologien und Nachhaltigkeit, sowie Universitäten und private Unternehmen, was eine große Chance für die Schaffung eines soliden Netzwerks für Innovationen bietet. Aufgrund der hohen Konzentration von Ausbildungsstätten drängt eine große Zahl gut ausgebildeter junger Menschen mit den erforderlichen Fähigkeiten auf allen Ausbildungsebenen kontinuierlich auf den Arbeitsmarkt. Daher verfügt die Oberrheinregion über reichlich Humanressourcen für einen nachhaltigen technologischen Wandel. Darüber hinaus sind die schnellen Verbindungen zwischen Österreich (täglich), Frankreich (täglich), der Schweiz (täglich), Spanien (wöchentlich), Luxemburg (wöchentlich), Belgien (wöchentlich), den

Niederlanden (wöchentlich) und Italien (wöchentlich) für junge Europäerinnen und Europäer, die in der Oberrheinregion zeitlich befristet oder vollständig arbeiten wollen, attraktiv.

Fünftens: Der Aachener Vertrag enthält Experimentierklauseln, mit denen gezeigt werden kann, wie eine erfolgreiche grenzüberschreitende Integration (CBRIS) zum Mehrwert einer gemeinsamen Innovationsindustrie beiträgt.

Zusätzlich zu den bereits erwähnten regionalen Vorzügen weisen die lokalen Stärken in und um Fessenheim, wie das Vorhandensein von Häfen, Verkehrsinfrastruktur, Industrien und deren Fabriken, auf das hohe Potenzial der Region hin, ein europäisches Vorbild für die regionale Transformation zur Nachhaltigkeit zu werden.

Der Erfolg der Umsetzung der empfohlenen Pilotprojekte in den verschiedenen Innovationsbereichen basiert jedoch auf zwei Eckpfeilern: der Tragfähigkeit eines Business Case für die ersten privaten Akteure, der Sichtbarkeit, sowie der gesellschaftlichen Unterstützung und Akzeptanz. Wenn alle diese Voraussetzungen erfüllt sind und die politische Unterstützung gegeben ist, wird die Umsetzung der empfohlenen Pilotprojekte für einen nachhaltigen, CO₂-neutralen Wirtschaftsraum möglich sein.

03. Potenziale für erneuerbare Energien in der Oberrheinregion

Im Laufe der Zeit haben die erneuerbaren Energieressourcen einen wichtigen Beitrag zur gesamten Primärenergieversorgung auf globaler Ebene zu leisten (Gernaat et al., 2021). Die Verfügbarkeit von erneuerbaren Energien wird immer mehr zu einer Voraussetzung für eine erfolgreiche Transformation durch Investitionen. Der Erfolg der Pilotimplementierung ist daher direkt mit der Verfügbarkeit von grüner Energie verbunden. Daher enthält der Bericht ein Kapitel, in dem das technische Potenzial für erneuerbare Energien in der Oberrheinregion abgeschätzt wird.

Das Europäische Parlament definiert auf seiner Website erneuerbare Energiequellen als: Windkraft, Solarenergie, Wasserkraft, Meeresenergie, geothermische Energie, Biomasse und Biokraftstoffe. Im Juli 2021 schlug die Europäische Kommission vor, den Anteil der erneuerbaren Energien am EU-Energiemix im Rahmen ihrer verbindlichen Ziele in der Erneuerbare-Energien-Richtlinie zu erhöhen und erneuerbare Kraftstoffe wie Wasserstoff zu fördern (EUROPA - Europäische Kommission, 2021). In einer Studie, die im Rahmen des Interreg-Oberrhein-Projekts "RES-TMO" durchgeführt wurde, wurde das technische Potenzial für die Erzeugung erneuerbarer Energien in der Oberrheinregion untersucht und die wichtigsten Ergebnisse werden hier wegen ihrer herausragenden Bedeutung für den gesamten Transformationsprozess aufgeführt.

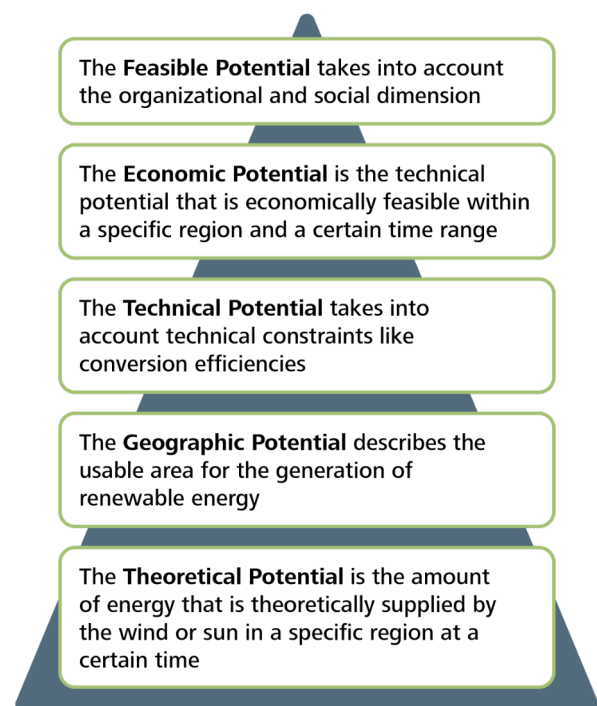


Abbildung 2: Die Potenzialhierarchie, wie sie von Jäger et al. (2016) definiert und im Rahmen des RES-TMO-Projekts angepasst wurde

Was die Schätzung des Potenzials an erneuerbaren Energien betrifft, so ist es wichtig, zunächst zu beschreiben, was mit erneuerbaren Energien (wie oben definiert) und Potenzialen gemeint ist. Die Potenzialhierarchie ist in der oben stehenden Abbildung mit den Definitionen nach Jäger et al. (2016) zu sehen. Zu den Potenzialen gehören: theoretische, geografische, technische, wirtschaftliche und realisierbare Potenziale. Die Untersuchungen im Rahmen des RES-TMO-Projekts enden auf der Ebene des technischen Potenzials, da die letzten Ebenen (wirtschaftlich und machbar) von Fall zu Fall untersucht werden müssen. Das technische Potenzial berücksichtigt die Landnutzungs-, System- und topografischen Zwänge sowie die technologischen Zwänge für Energiesysteme (Lopez et al., 2012).

Wichtige Ergebnisse

Wind: Die vorläufigen Ergebnisse zeigen, dass das technische Potenzial für die Windenergieerzeugung in der Oberrheinregion 128 TWh pro Jahr beträgt. Auf Länderebene ist das technische Potenzial der Windenergie in Frankreich und Deutschland relativ höher als in der Schweiz. Der gesamte jährliche Energiebedarf in der Oberrheinregion wurde auf etwa 212,41 TWh/Jahr geschätzt, der theoretisch zur Hälfte durch Windenergie gedeckt werden könnte. Es ist jedoch wichtig zu erkennen, dass die wirtschaftlichen und regulatorischen Bedingungen sowie die gesellschaftliche Akzeptanz der Technologie das technische Potenzial der Windenergie in der Region begrenzen und verringern, sodass realistischere nicht mehr als 10 % des technischen Potenzials erwartet werden kann.

Solar-Photovoltaik (PV): Die zweite wichtige erneuerbare Energiequelle in der Region ist die solare Photovoltaik. In der RES-TMO-Studie wurde das solare PV-Potenzial am Oberrhein in zwei Kategorien unterteilt: Hausdach-PV und Freiflächen-PV. Die Freiflächen-PV wurde wiederum in zwei Unterkategorien unterteilt, die von der Flächennutzung abhängen: Bodenmodule-PV und landwirtschaftliche (Agri)-PV.

1. Hausdach-PV: Im Rahmen des RES-TMO-Projekts wurde das technische Potenzial der Hausdach-PV auf 52 TWh pro Jahr geschätzt, was theoretisch etwa 24% des gesamten Energiebedarfs decken kann. Das gesamte technische Potenzial wird jedoch durch Einschränkungen, wie die Tragfähigkeit von Dächern, Abschattungseffekte und geschützte Denkmäler sowie die Bereitschaft der Bürger, in die Anlagen zu investieren, begrenzt. Die gesellschaftliche Akzeptanz für diese erneuerbare Energiequelle ist verhältnismäßig hoch (Cousse, 2021). Es wäre ein Erfolg, wenn langfristig 40% bis 50% der Dächer mit Solarzellen belegt werden könnten; dies ist jedoch nur unter besten Rahmenbedingungen möglich.

2. Freiflächen-PV: Das technische Potenzial der Freiflächen-PV wird in zwei Unterkategorien unterteilt: Agri-PV und Bodenmodule-PV. Der wesentliche Unterschied zwischen den Beiden ist, dass Agri-PV die Doppelnutzung von Ackerland für die Energie- und Nahrungsmittelproduktion berücksichtigt. Das geschätzte vorläufige technische Potenzial für Freiflächen-PV (159,5 TWh pro Jahr) ist groß, aber nur ein kleiner Prozentsatz der berechneten Nutzfläche kann mit PV-Anlagen bedeckt werden, da die Abstände zwischen den Reihen sowie ökologische und gesellschaftliche Aspekte noch nicht berücksichtigt wurden. In der Potenzialhierarchie sind die wirtschaftlichen und realisierbaren Potenziale deutlich begrenzter als das technische Potenzial. Wenn 50 % des technischen Potenzials der Solarenergie als Freiflächen-PV genutzt werden, ist ein signifikanter Beitrag von fast 80 TWh pro Jahr zum Gesamtenergiebedarf der Oberrheinregion möglich.

Wasserkraft: Eine weitere erneuerbare Energiequelle, die im Rahmen des RES-TMO-Projekts untersucht wurde, ist die Wasserkraft. Das Projekt kam zu dem Schluss, dass der Beitrag der Wasserkraft in Höhe von 13,6 TWh pro Jahr begrenzt ist, da die Wasserkraftressourcen in der Region bereits intensiv genutzt werden und nahezu erschöpft sind, wie von Energieexperten auf beiden Seiten des Rheins bestätigt wurde.

Biomasse: Biomasse wird heute zunehmend als Ersatz für fossile Brennstoffe im Verkehrs- und Energiesektor eingesetzt. Im Vergleich zu fossilen Brennstoffen hat sie den Vorteil, dass sie in Europa regional verfügbar ist und gespeichert werden kann. Letzteres ist ein Vorteil im Vergleich zu den intermittierenden erneuerbaren Energiequellen wie Wind und Sonne. Das Projekt RES-TMO stützte sich bei seiner Schätzung auf das Projekt Qui-Biomass (Schumacher et al. (Eds.), 2017), in dem das Biomassepotenzial in derselben Region eingehend untersucht wurde. Das geschätzte Biomassepotenzial von 5,2 TWh pro Jahr und ist eher begrenzt.

Geothermie: Eine weitere erneuerbare Energiequelle ist die Geothermie. Bei den geothermischen Energiequellen kann zwischen Technologien unterschieden werden, die den flachen Untergrund (10 bis 100 Meter Tiefe) nutzen und Methoden, die den tiefen Untergrund (Tausende von Metern Tiefe) für die Energiegewinnung nutzen. Die oberflächennahe Geothermie wird in der Regel zur Bereitstellung von Heiz- oder Kühlenergie genutzt, während die tiefe Geothermie sowohl zur Stromerzeugung als auch zur Raumheizung eingesetzt werden kann (Miočić, 2021). Die in der TMO-Region (Trinationale Metropolregion Oberrhein) durchgeführte Studie deutet darauf hin, dass, obwohl in der TMO-Region bereits mehrere Erdwärmepumpen installiert sind, noch viele Einfamilienhäuser in der Region mit Erdwärmepumpen geheizt und gekühlt wer-

Tabelle 2a: Geschätzter Energieverbrauch in der Oberrheinregion.

URR	Population in 2019*	Final Energy Demand in 2016 in MWh/capita**	Energy Demand in URR in MWh/yr***	Energy Demand in URR in TWh/yr***
Switzerland	1.507.718	49	73.878.182	73,88
Germany	2.858.606	26	74.323.756	74,32
France	1.888.480	34	64.208.320	64,21
Total	6.254.804		212.410.258	212,41

Tabelle 2b: Technisches Potenzial der erneuerbaren Energien in der Oberrheinregion

RE Source	Annual Potential (in TWh/yr)
Wind	128,0
Solar PV Rooftops	52,2
Solar PV Agro	91,5
Solar PV GM	68,0
Biomass	5,2
Hydropower	13,6

den könnten, insbesondere in Verbindung mit einer zukunftsicheren Niedrigenergiesanierung. Eine Erhöhung des Anteils, der in der TMO eingesetzten *Ground Source Heat Pumps (GSHPs)*, kann daher eine drastische Reduzierung der Kohlenstoffemissionen im Zusammenhang mit der Raumheizung und -kühlung ermöglichen (Miočić, 2021). Die Effizienz von geothermischen Tiefenbohrungen hängt davon ab, wie tief die heißen Fluide gefunden werden und welche Eigenschaften das Gestein hat, aus dem die Fluide gewonnen werden. Geologisch gesehen weist die TMO-Region eine hohe Wärmestromdichte auf, die zu hohen Temperaturen im verhältnismäßig flachen Untergrund führt und stellt somit eine ideale Region für die Nutzung der Tiefengeothermie dar (Harlé et al., 2019). Die gesellschaftlichen Bedenken hinsichtlich des Erdbebenrisikos müssen allerdings ernsthaft berücksichtigt werden, um die technischen Potenziale in Machbarkeitspotenziale umzuwandeln.

Tabelle 2 gibt einen Überblick über die Schätzungen des Energiebedarfs und des technischen Potenzials der erneuerbaren Energiequellen in der Oberrheinregion.

Schlussfolgerungen

Zusammenfassend lässt sich sagen, dass sich das vorläufige technische Potenzial der erneuerbaren Energiequellen in der Oberrheinregion auf 358,5 TWh pro Jahr beläuft. Theoretisch könnte der gesamte jährliche Energiebedarf des Oberrheins gedeckt werden, ohne dass das geothermische Potenzial schon berücksichtigt ist.

Das technische Potenzial wird in hohem Maße durch Faktoren wie Landnutzungskonkurrenz für die Nahrungsmittelproduktion, Umweltauswirkungen, landschaftliche Aspekte, gesellschaftliche Akzeptanz, wirtschaftliche Rahmenbedingungen, Vorschriften und andere begrenzt. Für konkrete Planungen muss wie bereits erwähnt, eine realistischere Einschätzung, bezogen auf das wirtschaftliche und das machbare Potenzial umgesetzt werden. Das technische Potenzial unterstützt jedoch die Entwicklung besserer Rahmenbedingungen und Freiräume zur effektiven Nutzung der Potenziale durch einen integrativen Ansatz mit starker Beteiligung von Bürgern und Unternehmen. Basierend auf diesem Wissen über die Potenziale für erneuerbare Energien in der Oberrheinregion wurden die Pilotideen innerhalb der definierten Felder für Innovationszentren entwickelt und ihre Ergebnisse werden in den nächsten Kapiteln vorgestellt.

04. Grüne Batterien durch Material- und Kreislaufwirtschaft

Die für den Aufbau einer Kreislaufwirtschaft von Materialien für Lithium-Ionen-Batterien erforderlichen Pilotanlagen werden im Folgenden vorgestellt. Die Verbindungen (siehe Abbildung 3) zwischen diesen Pilotanlagen, sowie die Verbindungen zu den von den anderen Kompetenzgruppen vorgeschlagenen Pilotanlagen, werden hervorgehoben. Darüber hinaus werden die spezifischen Vorteile, welche die jeweiligen Pilotanlagen in der Region Fessenheim unterstützen, diskutiert.

Lithium-Ionen-Batterien spielen eine entscheidende Rolle bei der Verwirklichung eines nachhaltigen und kohlenstoffneutralen Energiesektors. Da die Lithium-Ionen-Batterie derzeit die am weitesten entwickelte fortschrittliche Batterietechnologie ist, wird sie vor allem in Elektrofahrzeugen (EV) eingesetzt. Betrachtet man die in Abbildung 4 dargestellte Prognose für veraltete Batterien, so lässt sich feststellen, dass die Umsetzung einer Kreislaufwirtschaft für Lithium-Ionen-Batterien bei möglichen Pilotanlagen in der Region Fessenheim Vorrang haben sollte.

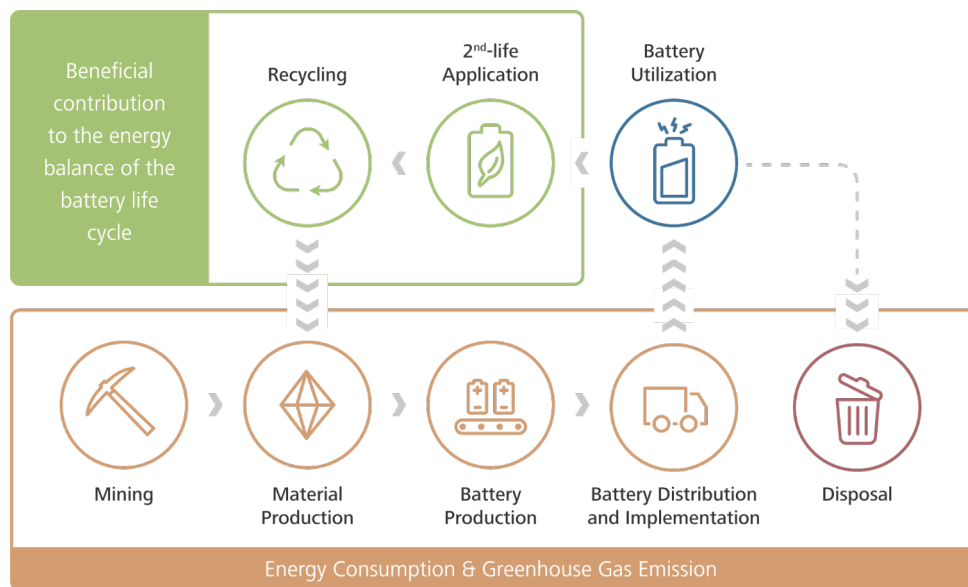


Abbildung 3: Lebenszyklus einer Batterie (Dühnen et al., 2020)

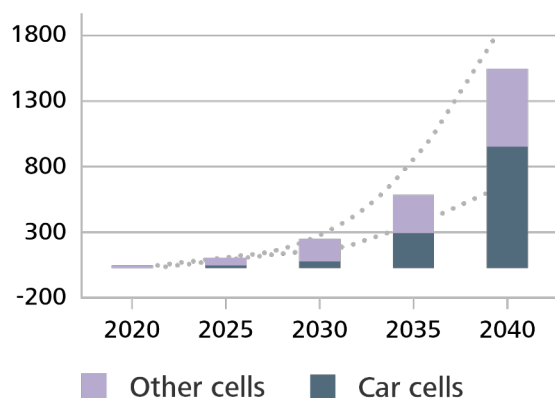


Abbildung 4: Prognose der LIBs-Recyclingströme in kt (hoch und niedrig) bis 2040 (in Anlehnung an Neef et al., 2021)

¹Die Kreislaufwirtschaft (Circular Economy, CE) ist ein regenerativer Ansatz, der auf die Verringerung von Abfällen abzielt und die ökologische Nachhaltigkeit von Produkten nach ihrer Nutzung gewährleisten soll (Mossali et al., 2020).

Um eine Kreislaufwirtschaft, wie in Abbildung 3 dargestellt, zu etablieren, schlägt die Kompetenzgruppe (CG) Green Batteries vor, sich auf die folgenden Bereiche in Fessenheim und dem Oberrhein zu konzentrieren:

- Herstellung von Hochleistungsbatteriematerialien mit geringem ökologischem Fußabdruck unter Verwendung neuer und wiederverwendeter Materialien
- Qualifizierung von gebrauchten Elektrofahrzeugbatterien für eine mögliche Second Life-Nutzung
- Installation eines elektrischen Energiespeichers mit der Integration von Second Life Elektrofahrzeugbatterien
- Entwicklung einer innovativen Demontage- und Recyclinganlage für Batterien am Ende ihrer Lebensdauer

Auf der Grundlage der vorgenannten Punkte wurden drei Hauptpiloten ermittelt:

- **Pilotprojekt 1:** Infrastruktur für die Zweitverwertung von Elektrofahrzeugbatterien, bestehend aus zwei Pilotanlagen - einem Qualifizierungszentrum für Second Life Elektrofahrzeug-Batteriesysteme und einer Hybrid-Energiespeicheranlage (EES), die mit Second Life Elektrofahrzeug Batterien ergänzt wird.
- **Pilot 2:** Infrastruktur für die Demontage und das Recycling von Batterien, bestehend aus zwei Pilotanlagen - einer Anlage für die Demontage von Batterien, einschließlich Diagnose und einer Anlage für das Recycling von Batteriematerialien
- **Pilot 3:** Eine Fabrik für Hochleistungsbatteriematerialien

Es ist wichtig darauf hinzuweisen, dass nur ein ganzheitlicher Ansatz für alle Pilotanlagen zu den gewünschten Synergieeffekten und den hohen wirtschaftlichen und ökologischen Vorteilen führt. Die vorgeschlagenen Anlagen ergänzen sich gegenseitig und bieten erhebliche Geschäftsmöglichkeiten. Wenn nicht alle vorgeschlagenen Anlagen in unmittelbarer Nähe zueinander errichtet werden, führt dies zu einem geringeren Nutzen für die Region und beeinträchtigt ihre Wettbewerbsfähigkeit in der Kreislaufwirtschaft für Batterien.

Die vorgeschlagenen integrierten Pilotanlagen weisen zahlreiche Verbindungen auf, die hauptsächlich den Austausch von Materialien und technologischem Know-how betreffen. Darüber hinaus würden alle diese Anlagen stark von der bestehenden Verkehrsinfrastruktur der Region profitieren, insbesondere von den Häfen entlang des Rheins, die einen großen Vorteil für den großräumigen

und wirtschaftlichen Transport von Erzen oder gebrauchten Batterien bieten. Das hybride *Electrical Energy Storage* EES-Pilotprojekt der Untergruppe "Second Life" könnte idealerweise an die Netzinfrastruktur am alten Standort des Kernkraftwerks angeschlossen werden, aber alternativ auch die Netzinfrastruktur anderer stillgelegter Kraftwerke nutzen. Die von der Untergruppe "Recycling" und "Batteriematerialien" vorgeschlagenen Anlagen haben einen hohen Energiebedarf, der durch erneuerbare Energiequellen gedeckt werden sollte. Das erhebliche Potenzial von erneuerbaren Energien wurde im Rahmen des RES-TMO-Projekts bewertet und in Abschnitt 3 erörtert. Zudem werden die vorgeschlagenen Pilotanlagen von den Forschungsinstituten und Universitäten der Region profitieren, da diese das erforderliche Fachwissen über Batteriematerialien liefern können. Die vorgenannten Bedingungen machen die Region zu einem idealen Umfeld für die Zusammenarbeit mit Unternehmen, die bereit sind, in solche Anlagen zu investieren. Nicht zuletzt gibt es Verbindungen zu den Pilotanlagen, die von den Kompetenzgruppen Grüner Wasserstoff und Smart-Grids vorgeschlagen und in den folgenden Abschnitten diskutiert werden. Ein Beispiel ist das selten genutzte, aber allgegenwärtige Nebenprodukt Sauerstoff, das bei der Wasserstoffsynthese anfällt und ein notwendiges Reagenz für die Herstellung von Batteriematerialien ist. Ein weiteres Beispiel ist die hybride *Electrical Energy Storage* (EES), die von der Untergruppe Second Life erdacht wurde und in ein intelligentes Stromnetz integriert werden könnte.

Zum einen bietet die Region Fessenheim günstige Voraussetzungen für die Errichtung von Pilotprojekten. Zum anderen kommen die sicheren Arbeitsplätze, die durch die geplanten Anlagen entstehen, der Region Fessenheim zugute. Im Bereich der Batterietechnologien (vor allem LIBs) gibt es keine Alternative zur Kreislaufwirtschaft, da der boomende Batteriemarkt in Zukunft zu einer Masse an veralteten Batterien führen wird. Ökologische, gesellschaftliche und wirtschaftliche Herausforderungen erfordern eine größere Infrastruktur für das Batterierecycling. Darüber hinaus, bietet das Batterierecycling weniger Abhängigkeit von außereuropäischen Rohstoffen sowie Wachstumschancen für die Wirtschaft in der Region. Wie in Abbildung 3 oben dargestellt, braucht die erwartete Entwicklung des LiB-Recyclingflusses angemessene Kapazitäten für die Weiterverwendung von Batterien, jedoch sind für das Batterierecycling die notwendigen Kapazitäten noch nicht geplant.

Empfehlungen

Um eine kreislaforientierte Batteriewirtschaft zu etablieren ist es entscheidend, die gesamte Verarbeitungslinie in der Region anzusiedeln. Daher wird empfohlen, ein Qualifizierungszentrum für Second-Life-EV-Batteriesysteme ein-

zurichten und es mit einem hybriden elektrischen Energiespeicher auf Nutzerebene zu verbinden, der durch Second-Life-Batterien ergänzt wird (Pilotprojekt 1). Dabei ist die Logistik für die Sammlung von Altbatterien und der Vertrieb der Second-Life-Batteriepacks an industrielle Nutzer mit zu berücksichtigen. Die oben erwähnte Pilotidee hat bereits eine hohe technologische Reife erreicht und ein Geschäftsmodell ist schnell umsetzbar. Es wird davon ausgegangen, dass dieses Pilotprojekt in naher Zukunft eingerichtet werden kann und dass es möglich sein könnte, bestehende Industriegebäude für die Einrichtung des Qualifizierungszentrums zu nutzen.

Für Pilot 2 wird die Einrichtung einer Pilotinfrastruktur als Testumgebung für künftige Industrieanlagen, die sich auf die Demontage und das Recycling von Batterien konzentrieren, empfohlen. Die Demontage ist ein Prozess, der eng mit der Qualifizierung von Batterien verbunden ist (Pilotprojekt 1) und automatisiert (mit Robotern) durchgeführt werden kann. Nach der Demontage basiert der erste Schritt des eigentlichen Batterierecyclings auf einem mechanischen Zerkleinerungsprozess (mechanische Zerkleinerung der Batteriezellen). Bei diesem Zerkleinerungsprozess fällt die so genannte schwarze Masse an, die zur Gewinnung der wertvollen Elemente (hauptsächlich Kobalt und Nickel) verwendet wird. Durch das Recyclingverfahren werden diese Elemente in einer Form gewonnen, die ihre Verwendung als Ausgangsmaterial für die Herstellung neuer Batteriematerialien ermöglicht (Pilot 3). Der gesamte Recyclingprozess sollte Diagnoseeinheiten umfassen, die für die Wiederverwendung der recycelten Materialien als Rohstoffe wichtig sind. Obwohl aus dem Recycling von Lithium-Ionen-Batterien wertvolle und kritische Rohstoffe für die Wiederverwendung gewonnen werden können, müssen noch viele Herausforderungen im Zusammenhang mit neuen Innovationen bewältigt werden. So hat auch die Batterieberatungsgruppe der kalifornischen Umweltschutzbehörde (CalEPA, n. d.) die Einrichtung von Demonstrationsprojekten für das Recycling von Lithium-Ionen-Batterien empfohlen (wie sie in Pilotprojekt 2 vorgeschlagen wurden) um das Wissen über die Leistung (d. h. Lebensdauer, Degradationsrate) und die Sicherheit der Recyclingprozesse zu verbessern. Diese Prüfstände werden dringend benötigt, um das Vertrauen der Öffentlichkeit zu stärken, die bestmögliche Nutzung der Materialien zu gewährleisten und ihre wirtschaftliche Machbarkeit zu testen. Es wird auch empfohlen, beide Pilotinfrastrukturen gleichzeitig zu errichten, um den gesamten Recyclingprozess in unmittelbarer Nähe zu einander zu prüfen.

Das Batterierecycling ist eng mit der Idee einer Batterie-materialfabrik verbunden (Pilotprojekt 3); daher wird die Infrastruktur für die Entwicklung und Produktion neuer Batteriematerialien aus recycelten Rohstoffen allein oder zusammen mit neuen Rohstoffen empfohlen. Die Innova-

tion, recycelte Rohstoffe aus Altbatterien in die Produktion neuer Batteriematerialien zu integrieren, ist eine zukunftsweisende Aufgabe und erfordert eine enge Zusammenarbeit zwischen Wissenschaft und Industrie.

Wir empfehlen, diese komplementären Pilotanlagen als Einheit zu realisieren, um die Vorteile der sich daraus ergebenden Synergien zu optimieren, insbesondere den Austausch von Materialien (Verringerung des Transports) und Know-how (neue Innovationen) (siehe Abbildung 5).

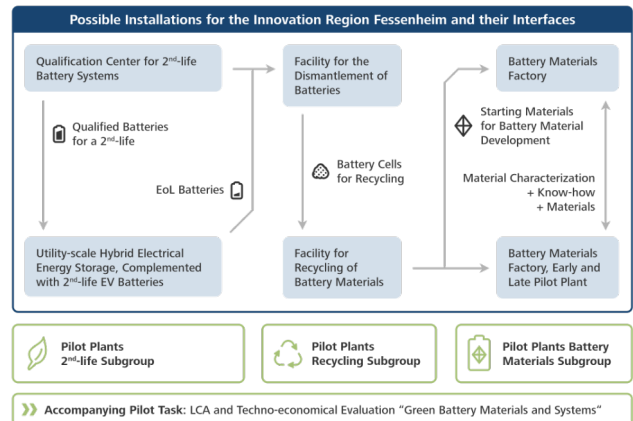


Abbildung 5: Von der Batteriekompetenzgruppe vorgeschlagenes Hauptpilotprogramm

Es ist wichtig zu beachten, dass der Bau dieser Anlagen große Investitionen erfordert. Die Industrie muss davon überzeugt werden, dass gemeinsame grenzüberschreitende Investitionen in Kombination mit EU-Finanzierungen im Rahmen des Green Deal eine Chance sind, umfangreichere Investitionsmittel zu erhalten und Investitionsprobleme besser zu bewältigen. Es wird dringend empfohlen, die vorgeschlagenen Pilotanlagen im Gebiet des Eurodistrikts Breisach - Biesheim - Fessenheim zu errichten. An diesem vorgeschlagenen Standort unterstützt die Hafeninfrastuktur tri-modale Kapazitäten für die Transportlogistik. Schließlich kann auf beiden Seiten der Grenze erneuerbare Energie für diese Infrastruktur installiert werden. Darüber hinaus gibt es aber weitere mögliche Standorte für die Umsetzung der entsprechenden Infrastrukturen im Oberrhein.

05. Multimodaler Wasserstoff-Hub Fessenheim

Der Einsatz von Wasserstoff als Energieträger bietet einzigartige Chancen für eine breitere Integration erneuerbarer Energien und eine optimierte Ressourcennutzung sowie die Schaffung zukunftsorientierter Arbeitsplätze. Seine Umsetzung sichert die Entwicklung der Region zu einem nachhaltigen und zukunftsweisenden CO₂-neutralen Wirtschaftsraum. Wasserstoff ermöglicht die saisonale Speicherung von erneuerbarem Strom und trägt durch die flexible und effiziente Kopplung der verschiedenen Sektoren zum Aufbau eines robusteren Energiesystems bei (Samsati & Samsati, 2019). Zudem sind in der Region um Chalampé und im Baselgebiet mehrere große Unternehmen angesiedelt, die Wasserstoff in ihren Prozessen einsetzen. Ein weiterer wichtiger Punkt ist, dass die Region reich an Komponenten, Projekten und regionalen Akteuren ist, die gemeinsam den multimodalen Wasserstoff-Hub bilden können und in der Lage sind die gesamte Wertschöpfungskette von der Produktion über den Vertrieb bis zur Nutzung abzudecken.

Diese Rahmenbedingungen sowie die Vielfalt und Komplementarität der Region wurden auf dem "South Rhine H2 Summit" deutlich, der im November 2021 in Biesheim (Haut-Rhin) von der Europäischen Gemeinschaft Elsass organisiert wurde. Die Ergebnisse der Studie zeigen, dass die Nachfrage der Industrie nach Grünem Wasserstoff deutlich höher ist als in anderen Sektoren. Außerdem kann der derzeit konventionell hergestellte Wasserstoff (relativ) einfach durch Grünen Wasserstoff ersetzt werden.

Daher wird vorgeschlagen, dass der Aufbau des multimodalen Wasserstoff-Hubs (siehe Abbildung 6) mit dem Aufbau von Großkapazitäten für die Elektrolyse beginnt. Der wachsende lokal verfügbare Ökostrom wird die Kosten für die Erzeugung von Grünem Wasserstoff senken. Des Weiteren könnten die Vorteile der wechselseitigen Nutzung der in der Region befindlichen Wasserkraftwerke mit Solar-PV deutlich gemacht werden, da die Wasserkraftwerke nachts und an sonnenlosen Tagen zur Stromerzeugung genutzt werden können.

Darüber hinaus werden in der Folge auch Importkapazitäten für ergänzenden Grünen Wasserstoff über den Rhein aufgebaut. Die robuste Versorgungsinfrastruktur und die Verfügbarkeit von Flüssigwasserstoff werden den Oberrhein zu einem Handelsplatz für grüne Energie machen, insbesondere in Verbindung mit dem Ausbau des containerbasierten Transports vernetzt mit einem multimodalen Transportsystem. In diesem Fall werden ideale Voraussetzungen für eine dezentralere Anwendung von Grünem Wasserstoff in der Region geschaffen, wie z.B. der Aufbau einer Flotte von Grünen Wasserstoff-Lkws für den Schwerlastverkehr oder die Dekarbonisierung des öffentlichen Verkehrs mit wasserstoffbetriebenen Bussen und Zügen. Auch eine zunehmend dezentrale Erzeugung und Nutzung von Grünem Wasserstoff sowie die Förderung

von sogenannten Wasserstoff-"Prosumern" im Agrarsektor werden die Entwicklung einer Wasserstoffregion fördern, indem sie die Wasserstofftechnologien der breiten Öffentlichkeit näherbringen und in der Region verankern.

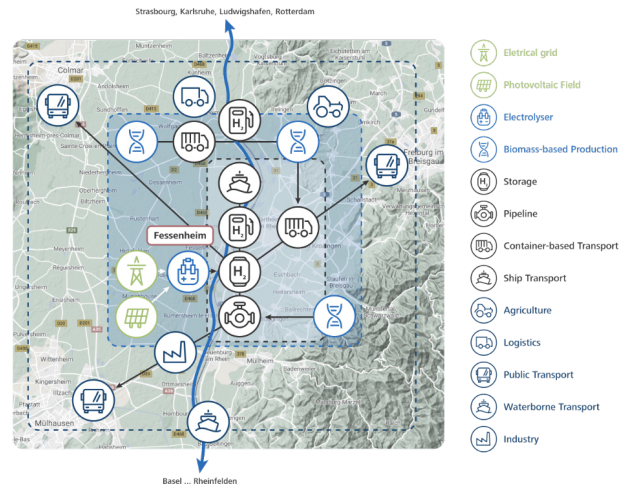


Abbildung 6: Hauptelemente des multimodalen Wasserstoff-Hubs in der Region Fessenheim

Basierend auf den oben genannten Überlegungen wird ein Multi-Modal Green Hydrogen Hub empfohlen, um die regionsspezifischen Produktions- und Anwendungsmöglichkeiten für Grünen Wasserstoff zu erkunden. Der Multi-Modal Green Hydrogen Hub soll sich auf die folgenden vier ergänzenden Pilotprojekte stützen, die die wesentlichen Merkmale eines funktionierenden Wasserstoff-Energiesystems abdecken:

1. **Pilotprojekt 1:** H2-A „Versorgung der Großindustrie mit Grünem Wasserstoff“
2. **Pilotprojekt 2:** H2-B „Virtuelle Pipeline“
3. **Pilotprojekt 3:** H2-C „Schwerlasttransport“
4. **Pilotprojekt 4:** H2-D „Dezentrale Produktion und Nutzung in der Landwirtschaft“

Empfehlungen

Zunächst empfehlen wir mit dem ersten Pilotprojekt 1 H2-A die Installation und den Betrieb einer großen 200-MW-Elektrolyseanlage in der Nähe von Ottmarsheim und dem Industriegebiet von Chalampé. Dieser Standort wird aufgrund seiner Nähe zum Industriegebiet von Chalampé und dem trimodalen deutsch-französischen Verkehrsknotenpunkt Ottmarsheim (Hafen, Eisenbahn und Autobahn) vorgeschlagen. Für eine anfängliche Leistung von etwa 30 MW wird vorgeschlagen, einen kleinen Teil der von den Wasserkraftwerken Ottmarsheim und Fessenheim (mit einer Nennleistung von jeweils 160 MW) erzeugten Elektri-

zität zu nutzen und mit einer schwimmenden Photovoltaikanlage zu kombinieren, die in den Wasserbecken dieser Kraftwerke installiert wird. Weitere schwimmende PV-Anlagen werden in einer späteren Phase auf mehreren künstlichen Kieselseen in der Umgebung vorgeschlagen. Das Elektrolyseursystem soll in der Nähe des Industriegebietes Chalampé installiert und über die bestehende Wasserstoffpipeline mit diesem Industriegebiet verbunden werden. Der gemeinsame Standort mit dem Kraftwerk Ottmarsheim ist optimal, da er den doppelten Vorteil bietet, die bestehende Wasserstoffverteilungsinfrastruktur zu nutzen und die angeschlossene Industrie schnell mit Grünem Wasserstoff zu versorgen. Schließlich sollte eine Erweiterung der lokalen Wasserstoffverteilungsinfrastruktur durch eine parallele Hochdruckleitung in Betracht gezogen werden, um die Kapazität der bestehenden Wasserstoffleitung zu erhöhen und die Versorgungsqualität zu verbessern, indem ein Druck von bis zu 100 MPa bereitgestellt wird, der für verschiedene Anwendungen, insbesondere im Verkehrswesen, von Nutzen ist (Verbindung zu Pilotprojekt H2-B und H2-C). Der hohe Druck ermöglicht kleinere und eigensichere Rohrquerschnitte und verwandelt die Pipeline in ein Zwischenspeichersystem.

Zweitens wird mit dem Pilotprojekt H2-B eine ergänzende Versorgung mit Grünem Wasserstoff über eine flexible Importoption empfohlen. Der Bau von langen Transferpipelines ist in der Regel mit enormen Kosten verbunden; außerdem sind solche Pipelines unflexible und starre Gebilde. Daher kommt das Pilotkonzept einer "virtuellen Pipeline" zum Tragen. Das Pilotprojekt H2-B schlägt den containerbasierten Batch-Transport von Wasserstoff über den Rhein vor. Mit der Containerlösung können Verluste durch den Transfer zwischen stationären und Transportbehältern vermieden werden und der nahtlose Übergang von gasförmigem Hochdruckwasserstoff zu dichterem flüssigem Wasserstoff (LH₂) wird ermöglicht. Da der containerbasierte Transport leicht von den Schifffahrtswegen auf ein multimodales Transportsystem über Schiene und Straße ausgeweitet werden kann, wird er dezentrale Anwendungen weit entfernt von den Bunkerstandorten im Industriehafen Ottmarsheim und/oder den Schifffahrtswegen von Fessenheim erschließen und die Wasserstoffverteilung flexibler, robuster und wirtschaftlicher machen. Darüber hinaus wird die Verfügbarkeit von kryogenem LH₂ als Katalysator für die weitere Erforschung, Entwicklung und Demonstration innovativer Lösungen dienen, z. B. die Verwendung von LH₂-gekühlten Supraleitern für hybride elektrische und chemische Energieübertragungsleitungen oder Speichersysteme. Über die virtuelle Pipeline am Rhein wird die Region Fessenheim direkt mit Rotterdam verbunden sein, die zum zentralen europäischen Anlandeort für LH₂ aus Übersee werden soll. Darüber hinaus wird der Import über die virtuelle Pipeline die potenzielle Versorgungslücke mit Grünem Wasserstoff, die durch die lokale Produktion entsteht, kostengünstig ausgleichen. In Anbe-

tracht dieser Punkte und mit den entwickelten Import- und Exportkapazitäten wird die Koordination der Region Fessenheim mit den verschiedenen industriellen regionalen Nachfragestandorten entlang und jenseits des Rheins möglich sein und somit als grenzüberschreitender Handelsstützpunkt für grüne Energie fungieren können.

Drittens hat die wichtige transnationale Straßeninfrastruktur, welche die Nordschweiz mit dem Grand Est in Frankreich und dem deutschen Südwesten verbindet, viele Transportunternehmen dazu veranlasst, Niederlassungen in diesem Gebiet zu betreiben. Um den beträchtlichen CO₂-Fußabdruck des regionalen Straßentransports zu reduzieren, wird mit dem Pilotprojekt H2-C empfohlen, einen On-Demand-Service zu etablieren, der Unternehmen nachhaltige, wasserstoffbasierte Transportkapazitäten anbietet. In Anlehnung an das Geschäftsmodell der Hyundai Hydrogen Mobility aus der Schweiz wird ein Dienstleistungsunternehmen eine Flotte von Wasserstoff-Lkws (anfänglich 20-30) erwerben und betreiben sowie die erforderliche Betankungsinfrastruktur aufbauen. Die Konzentration des Wasserstoffgeschäfts auf ein Dienstleistungsunternehmen wird einerseits helfen, bestmögliche Konditionen (Besteuerung, Wasserstoffpreise,...) auszuhandeln und andererseits den Kunden wirtschaftlich attraktive Pakete zu verkaufen. Entsprechend soll im Raum Ottmarsheim eine hochmoderne, LH₂-basierte Tankstelle (anfängliche tägliche Abgabekapazität von 1t, später 5t) errichtet werden. Die Station wird sich durch einen modularen Aufbau auszeichnen und soll aus einem eigenständigen, kommerziell betriebenen Teil und einem Forschungs- und Entwicklungsteil bestehen. Der kommerzielle Teil wird die Lkw-Flotte zuverlässig betanken und genügend Kapazität für kleinere Wasserstoffbusflotten bieten, die in Mühlhausen und/oder Freiburg betrieben werden, während der Forschungsteil flexible Schnittstellen und eine Infrastruktur für die Entwicklung weiterer Protokolle für die Schwerlastbetankung und für die Erprobung kritischer Komponenten wie Wärmetauscher und Dosiereinrichtungen bietet.

Viertens wird mit dem Pilotprojekt H2-D „Dezentrale Produktion und Nutzung in der Landwirtschaft“ der Einsatz von Agri-Photovoltaik (Agri-PV) zur lokalen Grünen Wasserstoffproduktion empfohlen. Der Einsatz von Agri-PV auf landwirtschaftlichen Flächen schafft direkte Vorteile für die Landwirte: Neben dem zusätzlichen Einkommen bietet Agri-PV für die Pflanzen sowohl Schutz vor direkter Sonneneinstrahlung als auch vor Sturm und Hagel (Fraunhofer ISE, 2020). Neben der Nutzung des durch Photovoltaik und Wasserkraft erzeugten Stroms wird empfohlen, die Nutzung von Biomasse für die lokale Erzeugung von Wasserstoff an einigen wenigen prototypischen Standorten weiter zu testen und zu entwickeln. Im Zusammenhang mit der Erzeugung von erneuerbarem Wasserstoff ist die Valorisierung von Biomasse ein vielversprechender

Ansatz, insbesondere wenn die Verwendung von valorisierten landwirtschaftlichen Bioabfällen vorgesehen ist. Darüber hinaus soll der Einsatz von Wasserstoff in der Landwirtschaft, vor allem in Landmaschinen mit umgerüsteten kraftstoffflexiblen Verbrennungsmotoren und in Kraft-Wärme-Kopplungsanlagen mit Hochtemperatur-Brennstoffzellen, demonstriert werden. Wasserstoff kann somit neue Möglichkeiten für das Geschäftsmodell der landwirtschaftlichen Genossenschaften als Kraftstoffhändler bieten.

Wie oben dargelegt, ergänzen sich die Pilotprojekte gegenseitig, da sie sich mit unterschiedlichen Produktions- und Anwendungsbereichen befassen, verschiedene Technologien hervorheben, die für eine planmäßige Umsetzung ausgereift genug sind, und genügend Potenzial für weitere Forschung und Innovation lassen. Obwohl die Projekte prinzipiell unabhängig voneinander durchgeführt werden könnten, wird das Gesamtsystem stark davon profitieren, wenn sie gemeinsam und in der vorgeschlagenen Reihenfolge umgesetzt werden.

06. Intelligente Stromnetze

In der Erwartung, dass intelligente Stromnetze weltweit Standard für die Steuerung von Stromnetzen werden, ist es notwendig intelligente Stromnetze weiter zu entwickeln, um mit Hilfe künstlicher Intelligenz und durch technologischen Fortschritt die Erzeugung und den Verbrauch von Strom optimieren zu können. Die Vorteile von intelligenten Stromnetzen sind vielfältig: Zum einen können sie neue Informations- und Kommunikationstechnologien wie vernetzte Objekte integrieren und sind daher in der Lage, Echtzeitinformationen über Stromverbrauch und -nutzung an die Netzbetreiber (Erzeuger, Verteiler und Verbraucher) zu übermitteln (Butt et al., 2021). Durch die Bereitstellung von Echtzeitinformationen über den Energiefluss ermöglichen intelligente Stromnetze den Netzbetreibern die Kontrolle, Steuerung, Analyse und Optimierung des Energieverbrauchs. Zum anderen ist das Ziel der intelligenten Stromnetze, diese gesammelten Informationen für die Anpassung des Stromflusses zu nutzen und so energieeffizientere Netze zu gewährleisten. Außerdem sorgen intelligente Stromnetze für ein Gleichgewicht zwischen Angebot und Nachfrage und verhindern eine Überhitzung der Netze. Schließlich können intelligente Stromnetze dazu beitragen, die Lücke bei der Umstellung der Energieressourcen von fossilen Brennstoffen auf erneuerbare Energien zu schließen (Butt et al., 2021).

Generell sind sowohl die Wasserstofftechnologien als auch die grünen Batterien, für die Echtzeitanalyse des Stromverbrauchs vollständig auf intelligente Stromnetze angewiesen. Darüber hinaus ermöglichen intelligente Stromnetze die Echtzeit-Optimierung des Energieverbrauchs, die Verringerung von Energieverlusten und die Optimierung der Integration von Batteriespeicherkapazitäten in das Netz zur besseren Stabilisierung des Netzes. An dieser Stelle sei darauf hingewiesen, dass intelligente Stromnetze uneingeschränkt für Technologien zur Nutzung erneuerbarer Energien geeignet sind, da sie durch die Integrierung verschiedener Quellen jederzeit angepasst werden können, ohne die Effizienz zu beeinträchtigen. Zudem tragen sie implizit zur Verringerung der Koh-

lenstoffemissionen bei. Es ist wichtig zu erkennen, dass ein intelligentes Strommanagement ein Schlüssel für die erfolgreiche Transformation des Energiemarktes ist (Bayindir et al., 2016).

Ziel der Kompetenzgruppe Smart-Grid ist es, das bestehende regionale transnationale Übertragungsnetz zu kartieren und Informationen über das raumbezogene Potenzial erneuerbarer Energien für die Entwicklung von Szenarien zur Wirkung auf die regionalen Energienetze zu nutzen. Darüber hinaus sollen die Potenziale des „Demand-Side-Managements“ untersucht werden, wozu es notwendig ist, mögliche Schwachstellen in der Energieverfügbarkeit zu identifizieren. Ideen zur Aktualisierung des Stromnetzverbindungskonzeptes zwischen Frankreich und Deutschland und zur Darstellung der Ausbaumöglichkeiten sind ein weiterer Schwerpunkt dieser Gruppe. Entsprechende Kartierungen und Modellierungen ermöglichen den Vergleich von technischen Alternativen beim Netz- und Anschlussausbau und unterstützen durch Hinweise zur Netzanpassung den Ausbau der erneuerbaren Energien. Die Entwicklung von diskreten Konzepten liefert auch verbesserte Ideen für die Optimierung der Übertragungskapazität bestehender Freileitungstrassen. Des Weiteren müssen die Untersuchungen zur Netzanpassung mit Analysen zur Systemsicherheit von Anlagen zur Erzeugung erneuerbarer Energie verbunden werden. Eine der größten Herausforderungen des grenzüberschreitenden Konzepts ist die Integration der fluktuierenden Stromerzeugung aus erneuerbaren Energien in das europäische Stromnetz. Ziel ist es daher, ein Stromübertragungsnetz zu konzipieren und zu betreiben, das sowohl flexibel als auch an unterschiedliche Stromerzeugungsanlagen angepasst ist. Für das grenzüberschreitende Innovationskonzept im Gebiet Fessenheim ist daher die Intention, das Stromübertragungsnetz so zu gestalten und zu betreiben, dass es an die unterschiedlichen Stromerzeugungsanlagen und die Anforderungen an mehr Flexibilität im Gesamtsystem angepasst ist.

Die Analyse der Kompetenzgruppe zeigte technische Herausforderungen auf, wie z. B. die vielfältige Energienutzung, die Sicherheit und Nutzung des Stromnetzes sowie die Netzintegration der Elektromobilität und weiterer Speicherkapazitäten. Zu diesen Herausforderungen gehören auch wirtschaftliche und gesellschaftliche Aspekte, wie geeignete Wirtschaftsmodelle, soziale Akzeptanz sowie rechtliche und sicherheitsrelevante Einschränkungen.

Um die regionalen Herausforderungen besser zu verstehen, organisierte die Kompetenzgruppe zwei Arbeitsseminare und verknüpfte die Ergebnisse mit weiteren Beiträgen aus Wissenschaft, Industrie und Gemeinden. Die Ergebnisse der Seminare wurden auf Ziele eingegrenzt, die im folgenden Text näher beschrieben werden und welche die Entwicklung der Pilotideen leiteten. So wurde deutlich, dass für die Weiterentwicklung von Smart-Grid-Anwendungen das bestehende grenzüberschreitende Netz kartiert werden muss, um potenzielle Schwachstellen im Zusammenhang mit zunehmenden Anteilen erneuerbarer Energien im Netz zu identifizieren, insbesondere im Hinblick auf die Anschlüsse und Stromlasten der verschiedenen nationalen Netzsysteme für die Mittel- und Niederspannungsebene. Erstens ist eine Netzplanung für die physische Ertüchtigung des bestehenden regionalen Stromnetzes erforderlich. Zweitens ist die Einrichtung von Testumgebungen für kleinere Nachbarschaftseinheiten wie Industrieparks oder Wohngebiete erforderlich, um die Funktionsweise intelligenter Netze durch die Integration von Speicherkapazitäten, wie stationären Batterien oder E-Autos, grundlegend zu verstehen und so mehr über die Herausforderungen des intelligenten Netzmanagements zu erfahren. Schließlich müssen die Funktionalität und die Auswirkungen intelligenter Netzsysteme auf die Netzstabilisierung und das effiziente Energiemanagement als Meta-Demonstrator in einer grenzüberschreitenden Situation getestet werden, wie es der EcoRhena-Park bieten könnte.

Am Oberrhein verorten sich die etablierten industriellen Akteure, die von den Energieerzeugern bis zu den Verbraucherindustrien (Energiemanagement, Chemie, Automobil usw.) reichen. Die dort vorhandenen Ingenieurdienstleistungen stellen einen Vorteil für die Entwicklung von Pilotprojekten für intelligente Stromnetze dar. Darüber hinaus sind in der Region die erforderlichen technischen und wissenschaftlichen Kompetenzen für die Durchführung der Pilotprojekte vorhanden. Ein weiterer Pluspunkt, der die Pilotprojekte unterstützt, ist das Engagement der lokalen Behörden und vieler Unternehmen für Strategien zur Veränderung von Industriestandorten oder Stadtvierteln, um deren Kohlenstoffauswirkungen zu verringern oder sogar die Zertifizierung nach ISO 50 001 (Energiemanagement) zu erreichen.

Um alle Herausforderungen und Möglichkeiten der Smart-Grid-Innovation in der Region Oberrhein zu erfassen, werden drei Pilotprojekte vorgeschlagen:

- **Pilotprojekt 1:** Einrichtung von gedoppelten nachhaltigen Quartieren in Mulhouse und Karlsruhe
- **Pilotprojekt 2:** Integration von Elektroladestationen für die Elektromobilität in ein intelligent gesteuertes Stromnetz als Nachbarschafts- und Meta-Demonstrationsprojekte.
- **Pilotprojekt 3:** Kartierung der regionalen Netzsituation und Modellierung von Zukunftsszenarien für die Verstärkung der regionalen Netze zum Austausch volatiler Elektrizität auf verschiedenen Spannungsebenen

Empfehlungen

Die Kompetenzgruppe Smart-Grids empfiehlt die Installation eines Smart-Grid-Systems (Abbildung 7) in zwei Stadtvierteln (Pilot 1) in Frankreich und Deutschland als Testumgebung für intelligente Netzmanagementbereiche wie den kontrollierten und effizienten Stromverbrauch nach Bedarf. Das Ziel ist die Integration von Smart-Grid-Systemen in Stadtteilen in Mulhouse und Karlsruhe. Die Standorte wurden ausgewählt, da die Kommunen bereit sind, ein solches Pilotprojekt durchzuführen: In Karlsruhe wurde bereits mit der Umsetzung der Smart-Grid-Nachbarschaft begonnen, während die Gemeinde Mulhouse bereit ist, in eine solche Idee zu investieren. Der Transfer des gewonnenen Know-hows aus den in den beiden Stadtvierteln getesteten Smart-Grid-Systemen in die geplante Umsetzung des deutsch-französischen Innovationsparks EcoRhena als Beispiel für einen grenzüberschreitenden Meta-Demonstrator, wird empfohlen. Mit diesem Pilotprojekt sollen folgende Ziele erreicht werden: Die Veranschaulichung, wie intelligente Stromnetze die Reduzierung des Energieverbrauchs befördern, sowie die Integration und intelligente Speicherung erneuerbarer Energien, die Kopplung von Stromquellen, Wärme- und Kältemanagement und die Schaffung exportfähiger Modelle unterstützen.

Die Gruppe empfiehlt, die Integration von E-Mobilitätsbatterien in das Smart-Grid-System zusammen mit der Umsetzung der Smart-Grid-Quartiere zu testen (Pilot 2), um Erkenntnisse über die Verbesserung des Stromnetzmanagements durch Integration zu erlangen und wie technische, wirtschaftliche und gesellschaftliche Hindernisse gelöst werden können. Die Ziele dieses Pilotprojekts sind die Verbesserung des Verständnisses für die Optimierung des Ladestationsnetzes eines Stadtteils und der Kopplung zwischen dem Ladelastnetz und dem Verteilungsnetz mit der Intention, Stromspitzen bei der Nutzung von Batterie-

riespeichern für die Elektromobilität zu reduzieren, das beste Profil und die besten Nutzungsmodelle zu erreichen und die grenzüberschreitende Standardisierung von Ladenetzen zu unterstützen. Des Weiteren soll untersucht werden, wie e-Mobilität zur Stabilisierung der Netze integriert werden kann. Es wird vorgeschlagen, mit Industrievierteln zu beginnen, indem elektrische Ladestationen als Testumgebung für Smart-Grid-Anwendungen eingerichtet werden. So könnte gezeigt werden, wie intelligent integrierte Ladestationen zur E-Mobilität beitragen können, Energie zu sparen und die Energieverteilung in Bezug auf Verfügbarkeit und Zugänglichkeit zu optimieren.

Eine weitere Empfehlung ist die Kartierung (Pilot 3) des bestehenden regionalen Stromnetzes und die Analyse seiner Schwachstellen für einen optimalen grenzüberschreitenden Stromaustausch sowie die Untersuchung seiner Fähigkeit zur Stabilisierung bei schwankender Stromerzeugung. Die Ziele dieses Pilotprojekts basieren auf der Energiepolitik der Euro-

päischen Union und umfassen die Stabilisierung des Netzes durch Beibehaltung der Frequenz von 50 Hz, die Optimierung und Dekarbonisierung der verschiedenen Energien und die Integration der lokalen Netze in die transnationalen. Die Kapazitäten der bestehenden Netze und Lastprofilsimulationen für die verschiedenen Szenarien von Anlagen zur Nutzung erneuerbarer Energien, die von der RES-TMO-Studie bereitgestellt werden, sollen Teil dieses Pilotprojekts sein.

Die Kompetenzgruppe Smart-Grids hat das Gasleitungsnetz nicht berücksichtigt, da es nicht im Fokus der Gruppe stand; sie empfiehlt aber, dieses Netzsystem im nächsten Schritt mit zu untersuchen, um eine integrierte Energiewende zu gewährleisten.

Schließlich benötigt jedes der vorgeschlagenen Pilotprojekte erhebliche Ressourcen und die Beteiligung von Netzbetreibern sowie von Gemeinden und der Industrie.

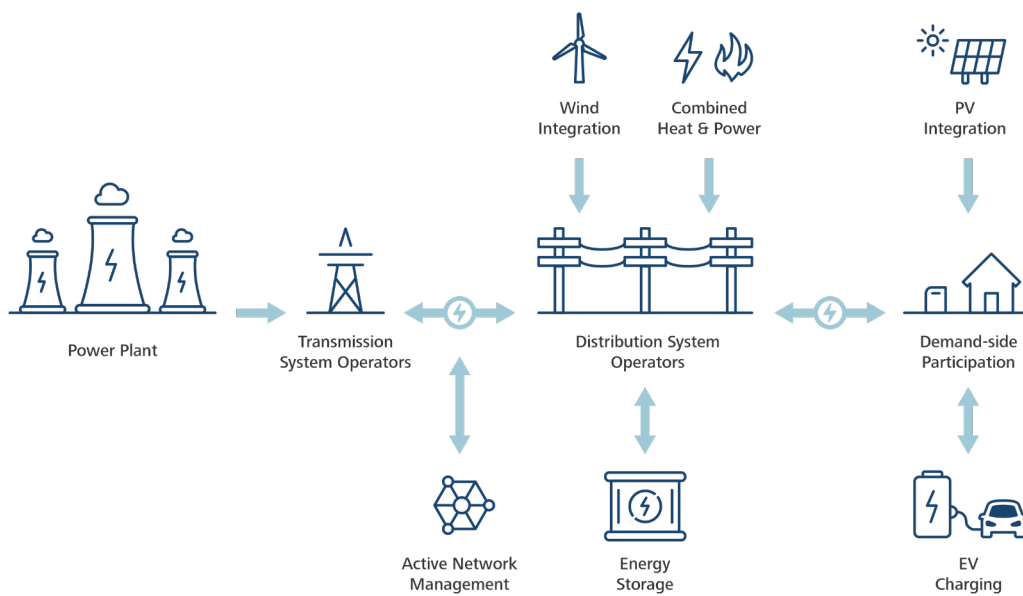


Abbildung 7: Eine mögliche Testumgebung für ein intelligentes Netzsystem in den Nachbarschaftspiloten (Quelle: European Distribution System Operators E.DSO).

07. Territorialer Rahmen

Innovative Ideen sind immer mit technologischen Herausforderungen verbunden und obwohl das grenzüberschreitende wissenschaftliche Fachwissen in der Oberrheinregion ein Pluspunkt bei der Bewältigung dieser Herausforderungen ist, ist die größte noch zu bewältigende die territoriale. Das Gebiet verfügt über eine hohe Komplexität, die durch seinen transnationalen Charakter noch verstärkt wird. Daher ist ein Rahmen mit mehreren Dimensionen erforderlich, in den das Gesamtprojekt eingebettet werden muss.

Die Kompetenzgruppe "Territoriale Rahmenbedingungen" ist eine multidisziplinäre deutsch-französische Forschungsgruppe, die sich auf folgende vier Themenbereiche stützt: soziale Akzeptanz, Umweltauswirkungen, territorialer Austausch und rechtliche Rahmenbedingungen. Zusammen definieren sie die Grundlage für die Innovationsregion Fessenheim. Diese Kompetenzgruppe soll die in den anderen drei Kompetenzgruppen der Machbarkeitsstudie entwickelten konkreten Ideen unterstützen (Abb. 8). Ihr Ziel ist es, ein umfassendes Bild aller territorialen Aspekte zu vermitteln, die sich auf das Projekt als Ganzes auswirken könnten. Die wichtigsten Ergebnisse werden in den folgenden Abschnitten zusammengefasst und mit möglichen Handlungsempfehlungen versehen.

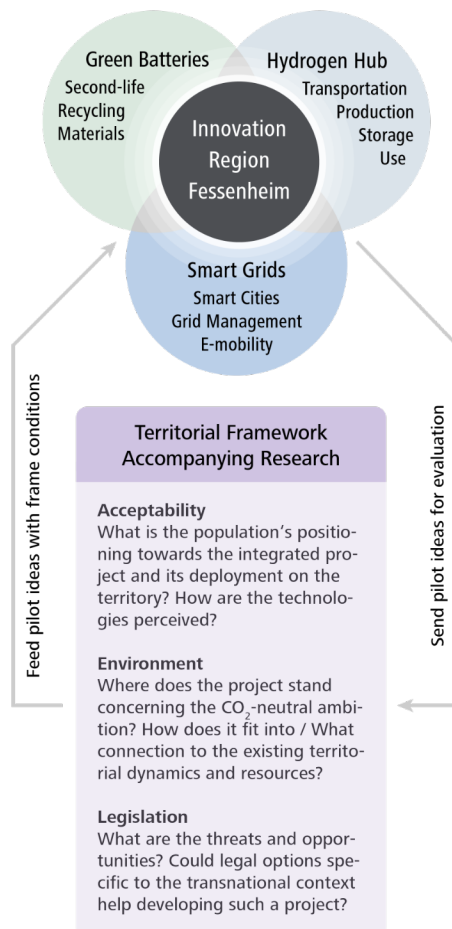


Abbildung 8: Die Verbindung zwischen der Gruppe "Territorialer Rahmen" und den anderen Kompetenzgruppen.

Empfehlungen

► Soziale Akzeptanz

Entscheidend für das Entstehen neuer Innovationen ist die soziale Akzeptanz (Patenaude, 2014). Gesellschaftliche Bedürfnisse, Wahrnehmungen und mögliche Veränderungen sowie ethische Fragen müssen dabei berücksichtigt werden. Die Untersuchungen dieser Kompetenzgruppe haben zu folgenden Ergebnissen geführt: Nachhaltige Technologien werden im Allgemeinen von der Öffentlichkeit unterstützt und Wasserstoff scheint die am meisten akzeptierte Technologie zu sein, gefolgt von grünen Batterien und intelligenten Netzen. Ein genauerer Blick auf die verschiedenen Parameter zeigt, dass objektives Wissen nur wenig mit dem Grad der Akzeptanz zu tun hat und dass das Vertrauen (in verschiedene Interessengruppen) einen bescheidenen, aber realen Einfluss hat. Die beiden vielversprechendsten Hebel mit positiver Wirkung scheinen das vermittelte Image (Affekt) und der damit verbundene Nutzen zu sein, da beide positiv mit dem Grad der Akzeptanz korreliert sind. In dieser Hinsicht ist Wasserstoff nicht nur die geeignetste Technologie, sondern vermittelt auch das positivste Image und scheint im Vergleich zu den anderen Beiden das beste Nutzen-Kosten-Verhältnis aufzuweisen.

Wir empfehlen daher eine sorgfältige Kommunikation. Je positiver das Image (positiver Affekt), desto wahrscheinlicher ist es, dass das Projekt als angemessen angesehen wird. Das gleiche Konzept gilt für den Nutzen: Je häufiger das Projekt als Quelle von Vorteilen wahrgenommen wird, desto eher wird es akzeptiert. Der Effekt ist bei den damit verbundenen Umweltvorteilen ohnehin noch stärker. Kommunikation ist der Schlüssel zum Aufbau des Images, das dann mit der Technologie/dem Projekt in Verbindung gebracht wird. Dementsprechend müssen die Kommunikationselemente eines Projekts sorgfältig konzipiert sein, um dieses Ziel zu unterstützen (Bostrom et al., 2018; Hoffrage & Garcia-Retamero, 2018; Peters et al., 2006).

Dennoch hängt die Akzeptanz auch von der Art und Weise ab, wie das Projekt in dem Gebiet umgesetzt werden soll. Die Einbindung der lokalen Bevölkerung von der Projektidee bis zur konkreten Entwicklung wäre zudem eine weitere Empfehlung. Dies geschieht am besten durch Transparenz zwischen dem Projektträger und der lokalen Bevölkerung und durch Konsultation bei der Projektentwicklung. Die Ko-Konstruktion des Projekts ist somit ein weiterer interessanter Hebel, den es zu erkunden gilt.

► Auswirkungen auf die Umwelt

Für die innovativen Projekte bedeutet die grüne Transformation eines Gebiets die geringsten Auswirkungen auf die Umwelt (Söderholm, 2020). Im Rahmen dieser Mach-

barkeitsstudie konnten nicht alle einzelnen Pilotprojekte bewertet werden. Aus diesem Grund wurde beschlossen, sich hauptsächlich auf die Folgenabschätzung der verschiedenen möglichen Szenarien für das Recycling von Lithium-Ionen-Batterien (LIB) und die verschiedenen bestehenden Wasserstoffproduktionsverfahren zu konzentrieren.

Das LIB-Recycling steckt noch in den Kinderschuhen, dient aber letztlich zwei Zielen: Begrenzung der Batterieentsorgung auf Mülldeponien und Verringerung des Drucks auf knappe Ressourcen (Harper et al., 2019). Es wurden vier Recyclingszenarien untersucht, die jeweils aus einer bestimmten Kombination von Elementarprozessen bestehen. Während die Daten zu den LIB-Recyclingverfahren noch spärlich sind, hat die Folgenabschätzung herausgestellt, dass aus ökologischer Sicht die verschiedenen Recyclingverfahren unterschiedlich starke Wirkungen haben. Darüber hinaus gibt es noch Spielraum für die Optimierung der Recyclingprozesse und die weitere Verringerung ihrer Umweltauswirkungen (Verwendung weniger umweltschädlicher Chemikalien). Interessant ist außerdem, dass andere innovative Technologien in Betracht gezogen werden sollten, da sie einen kürzeren Kreislauf im Modell der Kreislaufwirtschaft bilden könnten. So würde beispielsweise die direkte Neuaufbereitung von Batterien Vorteile haben, anstatt neue Batterien aus zurückgewonnenen Materialien herzustellen (Fan et al., 2021; Li et al., 2017). Es werden auch LEGO-ähnliche Batterien entwickelt, die die Demontage während des Recyclingprozesses erheblich erleichtern würden (Tarascon et al., 2021). Beide vorgenannten Technologien würden zu vergleichsweise geringeren Umweltauswirkungen führen.

Den Wasserstoff betreffend wurden mehrere Produktionsverfahren bewertet. Die Studie hat gezeigt, dass die Hochtemperatur-Elektrolyse unter Umweltgesichtspunkten der beste Kompromiss ist, insbesondere wenn die Infrastruktur durch ein Dampfnetz vor Ort versorgt wird. Die Herstellung von Wasserstoff durch Elektrolyse unterstützt das übergeordnete Ziel, die Treibhausgasemissionen zu verringern und sich in Richtung Kohlenstoffneutralität zu bewegen.

► Territorialer Austausch

Ein Gebiet ist eine lebendige Einheit, deren Austauschmöglichkeiten untersucht werden kann, um die mobilisierten Ressourcen zu analysieren und die territoriale Verankerung eines Projekts zu hinterfragen (Ribon et al., 2018). Die Auswahl relevanter Indikatoren ermöglicht es, die potenzielle Verbindung zu bestehenden territorialen Dynamiken zu messen und bevorzugte Umsetzungszonen zu identifizieren. Der Aufbau auf der bestehenden Industriestruktur und die Schaffung von Synergien durch Sektorkopplung ermöglichen ergänzende Vorteile, die

langfristig nicht nur alternative und de-karbonisierte Energiequellen bereitstellen, sondern auch die Produktionsmethoden der bestehenden Industrien de-fossilisieren (Ribon et al., 2018).

Das Projekt „Green Batteries“ basiert auf dem schnell wachsenden Markt der E-Mobilität. Der Ansatz der Kreislaufwirtschaft ist in dieser Hinsicht von wesentlicher Bedeutung und bietet interessante Perspektiven für die Lebensdauer und das Recycling von Batterien am Ende ihrer Nutzungsdauer. Die Größe der Pilotanlage deckt den derzeitigen Bedarf am Oberrhein (1 Tonne Autobatterien pro Tag), soll aber bei schnell wachsender regionaler Nachfrage langfristig auf 250 Tonnen pro Tag ansteigen. Darüber hinaus soll der Aufstellungsort der Anlage den technologischen Entwicklungen im Bereich des Batterierecyclings Rechnung tragen, die begleitend Raum für wissenschaftliche Experimente erforderlich machen. Die verschiedenen Technologien, die in das Projekt einbezogen sind, haben einen unterschiedlichen technologischen Reifegrad und unterschiedliche Zeitpläne. Während dieser Faktor zu potenziellen Synergien führen kann, können aber auch Störungen oder Abhängigkeiten auftreten, die berücksichtigt werden müssen. Die Technologien machen politische und industrielle Allianzen auch außerhalb des Oberrheins erforderlich. Darüber hinaus verfügt die Oberrheinregion über Mineralienvorkommen, die für Batterien wichtig sind und es wird empfohlen, diese Vorkommen von Primärressourcen, insbesondere von Lithium und Nickel, (erneut) zu erschließen.

Das Wasserstoffprojekt kann von einigen Synergiepotenzialen im Gebiet profitieren und könnte an mehreren Standorten umgesetzt werden, um ein Wasserstoff-Ökosystem zu entwickeln. Das Haupthindernis liegt jedoch in den lokal begrenzten Stromerzeugungskapazitäten, welche die hauptsächlich auf Elektrolyse basierende Wasserstoffherstellungskapazität behindern könnten. Die Nutzung von Biomasse-Ressourcen zur Wasserstoffherzeugung ist eine interessante Alternative, die mit den territorialen Ressourcen vereinbar ist und es wert ist, weiter verfolgt zu werden, auch wenn sie weniger ausgereift ist als die Elektrolyse. Dies gilt auch für andere innovative Produktionsverfahren (wie Biogas, Thermolyse, Thermo-cracking), die derzeit entwickelt werden und den Druck auf die lokalen Stromerzeugungskapazitäten verringern würden.

Das Smart-Grid-Projekt stützt sich hauptsächlich auf die Energieoptimierung. Die "Energienüchternheit" sollte auch für die Effektivität des intelligenten Netzes hervorgehoben werden, da sie wahrscheinlich der wichtigste Ansatz für den Aufbau eines widerstandsfähigen und klimaneutralen Stromnetzes ist.

Auf einer allgemeineren Ebene scheint die rasche Einführung dieser Projekte Folgendes zu erfordern: (i) einen gemeinsamen Konsens der betroffenen und/oder an der Entwicklung des Sektors beteiligten öffentlichen und privaten Interessengruppen, (ii) erhebliche und ausdrückliche öffentliche Unterstützung zur Begrenzung der mit den neuen Technologien verbundenen zusätzlichen Kosten, (iii) eine stärkere Beteiligung der privaten Interessengruppen, insbesondere beim Informationsaustausch, der für ein besseres Verständnis des aktuellen und potenziellen Bedarfs zur Entwicklung geeigneter Einrichtungen von entscheidender Bedeutung ist, und (iv) eine deutlichere Koordinierung mit der öffentlichen Politik auf verschiedenen territorialen Ebenen und mit den umliegenden Gebieten.

► Rechtlicher Rahmen

Die Umwandlung von Fessenheim in eine nachhaltige und innovative Region wirft rechtliche Fragen auf, die mit dem Vorhandensein von sowohl dem französischen als auch dem deutschen Rechtssystem verbunden sind. Es existieren innovative Lösungen innerhalb dieser Gesetzgebungen – diese müssen jedoch identifiziert und angewendet werden, um dieses Projekt zu entwickeln.

Die grenzüberschreitende Zusammenarbeit könnte der Schlüssel zur Entwicklung eines attraktiven rechtlichen Rahmens sein, der die Konkretisierung des Projekts begünstigt. Wenn rechtliche Hindernisse für die angestrebte grenzüberschreitende Kopplung nachhaltiger Technologien oder die Realisierung spezifischer Anlagen usw. festgestellt werden, könnte die grenzüberschreitende Zusammenarbeit als rechtliches Instrument fungieren, welches es Gebieten mit denselben Problematiken ermöglicht, gemeinsam mit Lösungen zu experimentieren und diese zu entwickeln. Bestehende französische rechtliche Möglichkeiten für innovative Projekte könnten angewandt und möglicherweise auf Deutschland ausgeweitet werden und umgekehrt. Andernfalls könnten neue Lösungen für beide Seiten entwickelt werden.

Um vorangegangenes zu veranschaulichen, dienen die folgenden Überlegungen: Im Fall von Wasserstoff scheint der französische Rechtsrahmen im Vergleich zum deutschen Rechtsrahmen sicher und gut entwickelt zu sein, da Wasserstoff im Mittelpunkt der französischen nationalen und regionalen Energiewende-Strategien steht (Langstädtler, 2021; Loi 2019-1147, 2019). Derzeit ist der französische Rechtsrahmen gut auf die Entwicklung von Pilotprojekten und die Förderung innovativer Projekte ausgelegt (Code de l'Énergie - Livre VIII; Ordonnance n°2021-167, 2021). Diese Neuerungen ermöglichen rechtliche Ausnahmeregelungen wie z. B. regulatorische „Sandkästen“ zur Überwindung möglicher rechtlicher Hindernisse. Die rechtlichen Hindernisse bedeuten lediglich eine rechtliche Abweichung vom französischen Recht.

Eine interessante Lösung für ein grenzüberschreitendes Projekt, das mit einem rechtlichen Hindernis konfrontiert ist, könnte in der Anwendung französischer Vorschriften bestehen, die derzeit einen besseren Rechtsrahmen bieten, als der deutsche Rechtsrahmen.

Bezüglich der Batterien ist für die Installation einer Produktionsanlage in beiden Rechtssystemen eine Genehmigung erforderlich, da Umweltbelange betroffen sind (BIMSchG o. D.; Code de l'environnement o. D.). Dieses langwierige und kostspielige Verfahren muss vor jeder konkreten Maßnahme berücksichtigt werden. Außerdem gibt es in Frankreich im Gegensatz zu Deutschland keine spezifischen Vorschriften für die Lagerung von Batterien, was ein ernstzunehmendes rechtliches Risiko für das Batterierecycling darstellen kann. Da Lithium als gefährliches Produkt gilt, sind geeignete Lagerungsmöglichkeiten und ein geregelter Transport erforderlich.

Grenzüberschreitende Projekte können von einem günstigen europäischen Kontext profitieren (Paket Saubere Energie für alle Europäer, 2019), sodass spezifische Mechanismen für die grenzüberschreitende Zusammenarbeit zur Anwendung kommen können. Die Innovationsregion Fessenheim kann als bilaterale Innovationszone entlang des Rheins betrachtet werden. Eine solche Entwicklung wird durch das EU-Energierecht gefördert (EUR-Lex energy, o. D.) und könnte von der Ausnahmeklausel im Aachener Vertrag (Aachener Vertrag - Art. 13, 2019) Gebrauch machen. Die Möglichkeit, eine Ausnahmeregelung anzuwenden hat jedoch ihre Grenzen um normatives Dumping zu vermeiden: Die Ausnahmeregelung muss strenge Umwelt- und Sozialstandards einhalten. Die Ausnahmeklausel des Aachener Vertrags spiegelt auch den politischen Willen der französischen und deutschen Staaten zur Zusammenarbeit wider. Im Wesentlichen muss auf den verfassungsrechtlichen Rahmen der Mitgliedstaaten als zwingende Rechtsgrundlage verwiesen werden.

Die technischen Pilotprojekte können größtenteils dazu genutzt werden, rechtliche und regulatorische Fragen und Hindernisse zu ermitteln und neue rechtliche und regulatorische Ansätze - auch auf europäischer Ebene - zu entwickeln, die für eine nachhaltige Ausweitung der technischen Lösungen erforderlich sind.

08. Schlussfolgerung

Die Machbarkeitsstudie hat gezeigt, dass die Innovationsregion Fessenheim mit einer Reihe von Vorzügen ausgestattet ist (siehe Kapitel 2), die ihr helfen könnten, sich zu einem europäischen grenzüberschreitenden regionalen Innovationssystem (CBRIS) zu entwickeln. Um die vorgeschlagenen Ideen effektiv für die Entwicklung zu nutzen, müssen die ausgewählten Pilotprojekte weiter ausgearbeitet werden, das heißt, die vorgeschlagenen Ideen müssen konkretisiert und für jedes einzelne Projekt spezifische Umsetzungspläne erstellt werden. Für eine detailliertere Planung der Piloten oder eine Auswahl von Piloten muss ein Konsortium mit Interessenvertretern auf kommunaler und europäischer Ebene und mit Industriepartnern gebildet werden, die über wissenschaftliches und administratives Know-how sowie über rechtliche Kompetenzen verfügen. Die ausgewählten Pilotprojekte aus verschiedenen Bereichen können zeigen, wie der Wandel zur Nachhaltigkeit mit den verschiedenen technologischen Innovationsbereichen verknüpft ist. So ist zum Beispiel die Erzeugung erneuerbarer Energien sowohl mit der Fähigkeit verbunden, Grünen Wasserstoff mit Hilfe der grünen Elektrizität zu produzieren als auch mit intelligenten Netzsystemen, eine optimale und bedarfsgerechte Verteilung des grünen Stroms mit minimalen Verlusten zu erreichen. Ebenso wichtig ist die Verbindung zwischen der Stabilisierung des Stromnetzes und der Verfügbarkeit von Batteriespeicherkapazität sowie die Verbindung zwischen der Batteriespeicherung und der Notwendigkeit des Recyclings von Batterien zum Schutz der Umwelt/des Klimas und zur Verringerung der Abhängigkeit von Rohstoffimporten. Unter Berücksichtigung der gegenseitigen Abhängigkeiten ist eine ganzheitliche Betrachtung der miteinander verknüpften Pilotprojekte und ihrer Umsetzung in einer Region unerlässlich, um etwas über den gesamten Transformationsprozess in Richtung Nachhaltigkeit zu erfahren. Die Wahl der Oberrheinregion mit ihren energieintensiven Industrieclustern um Basel, Chalampé und Karlsruhe ist ein optimaler Weg, um die Vorteile regionaler grenzüberschreitender Innovationszentren für mehr Nachhaltigkeit zu demonstrieren. Darüber hinaus bietet sie die Chance, nach der Stilllegung eines Kernkraftwerks (Fessenheim) zu demonstrieren, wie eine grenzüberschreitende Region durch die Bündelung der Ressourcen auf beiden Seiten der Grenze innerhalb eines kurzen Zeitraums in eine prosperierende, zukunftsorientierte Innovationsregion umgewandelt werden kann. Vor allem die Verringerung der Abhängigkeit von fossilen und nuklearen Energieträgern ist symbolisch für eine Region, die früher ein Kernkraftwerk im Betrieb beherbergte und vor allem für ihre Bürger, die in der Nähe dieses laufenden Kernkraftwerks lebten und sich stark mit diesem Thema auseinandersetzen. Außerdem weisen grenzüberschreitende Vorhaben viele Vorteile auf: Sie überwinden administrative und rechtliche Hindernisse, bieten regionales Fachwissen, das nationale Grenzen überwindet und beschleunigen so den Wissenstrans-

fer zwischen Unternehmen, Gesellschaften und Wissenschaftsorganisationen. Grenzüberschreitende Hubs erhöhen die grenzüberschreitende Flexibilität für Arbeitnehmer und vervielfachen die Ressourcen für gemeinsame Investitionen. Ebenso fördern diese das interkulturelle Verständnis, verbinden politische Visionen und stärken durch gemeinsame Aktivitäten die Position Europas in der Welt. Eine Reihe von Wirtschaftswissenschaftlern hat sogar nachgewiesen, dass die Wertschöpfung in grenzüberschreitenden Drehkreuzen signifikant hoch ist (Europäische Kommission, 2017).

Die Machbarkeitsstudie Innovationsregion Fessenheim skizziert erste mögliche Pilotprojekte, die auf der Grundlage der ermittelten regionalen Stärken entwickelt wurden. Die erfolgreichste Option ist die vernetzte Umsetzung dieser Pilotprojekte konzentriert in einer Region. Der Vorschlag liefert nicht nur Best-Practice-Beispiele, wie eine innovative Transformation in Richtung Nachhaltigkeit umgesetzt werden kann, sondern kann auch demonstrieren, wie Nationen auf beiden Seiten einer Grenze von gemeinsamen Aktivitäten profitieren können.

In der Tat bestätigten die Rückmeldungen der Industriepartner während mehrerer Workshops, dass die vorgeschlagenen Pilotprojekte mit den Zukunftsplänen ihrer Industrien übereinstimmen. In den Workshops betonten die Partner zudem, dass sie sich eine zeitnahe Durchführung solcher Pilotprojekte wünschen, um das Know-how zu gewinnen und für spätere Produktionsanlagen zu nutzen. Laut einer Erklärung von Frans Timmermans, Vizepräsident für den Europäischen Green Deal (2022)² „[wird] die grüne Transformation uns von unserer Abhängigkeit von Energie- und anderen Ressourcenimporten befreien. Insbesondere die Kreislaufwirtschaft wird es uns ermöglichen, unseren Bedarf an Primärressourcen zu senken und viel weniger Energie für unsere Produktion und unseren Konsum zu verbrauchen“.

Alle in der Machbarkeitsstudie vorgeschlagenen Pilotprojekte entsprechen dieser Aussage und tragen dazu bei, diese Vision zu erfüllen. Alle Piloten können nachgelesen werden und sind in Form von einzelnen Pilotblättern in einer eigenen Mappe als Anhang zu diesem Dokument beschrieben. Die Pilotblätter dienen als Grundlage für die Konkretisierung der Pilotideen. Ihre Umsetzungsplanung erfordert Investitionen, die vor allem als Anschubfinanzierung aus öffentlichen Mitteln von der europäischen bis zur regionalen Ebene gesichert werden müssen. Die Beschreibung der Piloten im Einzelnen kann als Grundlage zur Verfeinerung und Konkretisierung der Umsetzungspläne genutzt werden. Die für den Bau der Pilotanlagen notwendigen Investitionen sollten über öffentlich-private Finanzierungsmodelle abgesichert werden.

² <https://presidence-francaise.consilium.europa.eu/en/news/circular-economy-stakeholder-conference-the-eu-reaffirms-its-ambition-3-03/>

Um den oben erwähnten Prozess zu beschleunigen, müssen folgende Schritte nach Aussagen von Branchenmitgliedern zeitnah umgesetzt werden:

1. Bildung einer Managementgruppe zur Koordinierung und Verwaltung der Aktivitäten (einschließlich Öffentlichkeitsarbeit) für die Innovationsregion mit dem Ziel der Pilotumsetzung
2. Konkretisierung der Pilotideen durch Präzisierung der Umsetzungswünsche, wie z.B. die Zusammenstellung interessierter Konsortialmitglieder aus Wissenschaft, Wirtschaft, Verwaltung und gesellschaftlichen Akteuren für jedes Pilotprojekt
3. Ausarbeitung von Detail- und Ausführungsplänen für die Piloten
4. Bildung einer Lenkungsgruppe über alle Entscheidungsebenen aus Politik, Wirtschaft und Gesellschaft sowie regionale Akteure hinweg.
5. Bildung einer territorialen Rahmengruppe zur Begleitung der Umsetzungsplanung in Bezug auf ökologische, gesellschaftliche, verwaltungstechnische und ordnungspolitische Fragen
6. Durchführung von Maßnahmen zur Ansprache von Investoren und Erstellung eines Investitionsplans für Unternehmen sowie öffentliche und private Investoren
7. Festlegung eines Starttermins für die Pilotprojekte und die Öffentlichkeitsarbeit

Abschließend ist zu erwähnen, dass es zwingend erforderlich ist, die oben genannten Schritte innerhalb eines engen Zeitrahmens durchzuführen. Wie bereits erwähnt, haben die Rückmeldungen aus den Workshops mit den Branchenmitgliedern gezeigt, dass die Zeit das wesentliche Element ist, um die Führung auf dem Gebiet der technologischen Innovation hin zu mehr Nachhaltigkeit zu übernehmen und in diesem Jahrzehnt etwas zu bewirken.

Referenzen

- Aachener Vertrag (2019). *Traité entre la République française et la République fédérale d'Allemagne sur la coopération et l'intégration franco-allemandes*. Verfügbar unter: https://www.diplomatie.gouv.fr/IMG/pdf/traite.aix-la-chapelle.22.01.2019_cle8d3c8e.pdf
- Bayindir, R., Colak, I., Fulli, G., Demirtas, K. (2016). Intelligente Stromnetze Technologien und Anwendungen. *Renewable and Sustainable Energy Reviews*. (66),499-516.
- BlmSchG . n.d. Bundes-Immissions-Schutz-Gesetz Verfügbar unter: *BlmSchG - nichtamtliches Inhaltsverzeichnis*
- Bostrom, A., Böhm, G., O'Connor, R.E. (2018). Communicating risk: Principles and Challenges. In M. Raue, E. Lerner, & B. Streicher (Eds.), *Psychological Perspectives on Risk and Risk Analysis: Theory, Models, and Applications*. (251-278). Springer.
- Boons, F., Montalvo, C., Quist, J., Wagner, M. (2013). Sustainable innovation, business models and economic performance: an overview, *Journal of Cleaner Production*,(45),1-8, <https://doi.org/10.1016/j.jclepro.2012.08.013>.
- Butt, O.M., Zulqarnain, M., Butt, M.T. (2021). Jüngste Fortschritte in der Smart-Grid-Technologie: Zukunftsperspektiven für das elektrische Stromnetz. *Ain Shams Engineering Journal*, (12) 1. 687-695.
- CaLEPA n.d. Beratungsgruppe für das Recycling von Lithium-Ionen-Autobatterien. Verfügbar unter: <https://calepa.ca.gov/lithium-ion-car-battery-recycling-advisory-group/>
- Paket "Saubere Energie für alle Europäer", (2019). Verfügbar unter: https://energy.ec.europa.eu/topics/energy-strategy/clean-energy-all-europeans-package_en
- Code de l'environnement. n.d. Verfügbar unter: Code de l'environnement - Légifrance
- Code de l'Énergie - Livre VIII; Ordonnance n°2021-167 (2021). Ordonnance n° 2021-167 du 17 février 2021 relative à l'hydrogène. Verfügbar unter: <https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000043148001>
- Cousse, J. (2021). Immer noch verliebt in die Solarenergie? Installation size, affect, and the social acceptance of renewable energy technologies, *Renewable and Sustainable Energy Reviews*, (145), 111107.
- Dühnen, S.,Betz, J., Kolek, M., Schmuch, R., Winter, M., Placke, T. (2020). Toward Green Battery Cells: Perspective on Materials and Technologies. *Small Methods*. 4. 2000039. [10.1002/smt.202000039](https://doi.org/10.1002/smt.202000039).
- EC DG Mobility and Transport. n.d. Abgerufen am 27.02.2022 von https://transport.ec.europa.eu/index_en
- Europäische Kommission (2017). Quantifizierung der Auswirkungen von rechtlichen und administrativen Grenzhindernissen in Landgrenzregionen. Final report. Online verfügbar: https://ec.europa.eu/regional_policy/sources/docoffic/2014/boosting_growth/quantif_effect_border_s_obstacles.pdf
- Europäische Verteilernetzbetreiber (E.DSO) (n.d.). Verteilernetzbetreiber (DSOs). Verfügbar unter: <https://www.edsofsmartgrids.eu/home/why-smart-grid>
- Europa.eu. 2021. Mitteilung der Kommission an das Europäische Parlament, den Rat, den Europäischen Wirtschafts- und Sozialausschuss und den Ausschuss der Regionen "Fit für 55": Erreichung des EU-Klimaziels für 2030 auf dem Weg zur KlimaneutralitätCOM/2021/550 Abgerufen am 2. März 2022 unter: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0550>
- EU -lex Energy. n.d. Zugang zum Recht der Europäischen Union. Energie. Verfügbar unter: https://eur-lex.europa.eu/summary/chapter/energy.html?root_default=SUM_1_CODED=18
- Fan et al., 2021: Fan, Xiaoping, Chunlei Tan, Yu Li, Zhiqiang Chen, Yahao Li, Youguo Huang, Qichang Pan, Fenghua Zheng, Hongqiang Wang, et Qingyu Li. 2021. In A Green, Efficient, Closed-Loop Direct Regeneration Technology for Reconstructing the LiNi0.5Co0.2Mn0.3O2 Cathode Material from Spent Lithium-Ion Batteries. *Zeitschrift für gefährliche Materialien* 410 (mai): 124610. <https://doi.org/10.1016/j.jhazmat.2020.124610>.
- Fraunhofer-Institut für Solare Energiesysteme-ISE (2020). Agrivoltaik: Chancen für die Landwirtschaft und die Energiewende. Verfügbar unter: <https://www.ise.fraunhofer.de/content/dam/ise/en/documents/publications/studies/APV-Guideline.pdf>
- Gernaat, D.E.H.J., de Boer, H.S., Daioglou, V. et al. (2021) Autorenkorrektur: Auswirkungen des Klimawandels auf die Versorgung mit erneuerbarer Energie. *Nat. Clim. Chang*. (11), 362. <https://doi.org/10.1038/s41558-021-01005-w>
- Harlé P , Kushnir A. R.L., Aichholzer C., Heap M. J., Hehn R., Maurer V., Baud P., Richard A. , Genter A. & Düringer P. (2019), Heat Flow Density Estimates in the Upper Rhine Graben Using Laboratory Measurements of Thermal Conductivity on Sedimentary Rocks, *Geothermal Energy*, 7 (1): art. 38, doi: <https://doi.org/10.1186/s40517-019-0154-3>

- Hafenverwaltung Kehl. 2015. Deutsche Häfen am Oberrhein. Retrieved from: https://www.raonline.ch/pages/edu/st4/wawa_rhein0102a.html
- Harper, G., Sommerville, R., Kendrick, E., Driscoll, L., Slater, P., Stolkin, R., Walton, A., Christensen, P., Heidrich, O., Lambert, S., Abbott, A., Ryder, K.G., Gaines, L., Anderson, P. (2019). Recycling von Lithium-Ionen-Batterien aus Elektrofahrzeugen. *Nature*. 575 (7781), 75-86.
- Hoffrage, U., Garcia-Retamero R. (2018). Verbesserung des Verständnisses von gesundheitsrelevanten numerischen Informationen. In M. Raue, E. Lermer, & B. Streicher (Eds.), *Psychological Perspectives on Risk and Risk Analysis. Theory, Models, and Applications*. (279-298). Springer.
- Interreg Oberrhein (2019). Analyse des Programmgebiets INTERREG V OBERRHEIN Endbericht. 11.06.2019. Verfügbar unter: <https://www.interreg-oberrhein.eu/wp-content/uploads/3-analyse-des-programmgebiets.pdf>
- 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. doi: <https://doi.org/10.1016/j.renene.2016.05.013>.
- Jung, W., Engelke, D., Brester, B., Putlitz, A. 2012. Ulysses: Angewandte Forschungsergebnisse aus ESPON als Maßstab für die grenzüberschreitende Raumentwicklungsplanung nutzen. Wissenschaftlicher Bericht zum Abschlussbericht Multithematische Territorialanalyse der Trinationalen Metropolregion Oberrhein. ESPON & Karlsruher Institut für Technologie. Verfügbar unter: https://www.espon.eu/sites/default/files/attachments/ULYSSES_Final_Report_-_Scientific_Report_-_CS1_Upper-Rhine_MTA.pdf
- Komiyama, H., Takeuchi, K. (2006). Nachhaltigkeitswissenschaft: Aufbau einer neuen Disziplin. *Wissenschaft der Nachhaltigkeit 1* (1): 1-6.
- Langstädtler, S. (2021). Brauchen wir ein Wasserstoffinfrastruktur Gesetz? Zum planungs- und genehmigungsrechtlichen Rahmen für die Erzeugung, Verteilung und Speicherung von Grünem Wasserstoff. *ZUR Zeitschrift für Umweltrecht*. 32(4), 203-211.
- Li, X., Zhang, J., Song, D., Song L., Zhang, L. (2017). Direct Regeneration of Recycled Cathode Material Mixture from Scrapped LiFePO₄ Batteries. *Journal of Power Sources*. (345). 78-84. doi: <https://doi.org/10.1016/j.jpowsour.2017.01.118>.
- Lopez, A., Roberts, B., Heimiller, D., Blair, N., Porro, G. 2012. U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis. Technical Report NREL/TP-6A20-51946 July 2012. Available online: <https://www.nrel.gov/docs/fy12osti/51946.pdf>
- Loi 2019-1147 (2019). LOI n° 2019-1147 du 8 novembre 2019 relative à l'énergie et au climat. Verfügbar unter: LOI n° 2019-1147 du 8 novembre 2019 relative à l'énergie et au climat - Dossiers législatifs - Légifrance
- Miocic, J. (2021). Wasserstoffspeicherung im Oberrheingraben. Potenzialanalyse. Bericht Arbeitspaket 2.2. Verfügbar unter: https://www.res-tmo.com/fileadmin/PDFs/Outputs/RES_TMO_Bericht_H2_Speicherung_ORG_EN.pdf
- Mossali, E., Picone, N., Gentilini, L., Rodriguez, O., Manuel Pérez, J., Colledani, M. (2020). Lithium-Ionen-Batterien auf dem Weg zur Kreislaufwirtschaft: A Literature Review of Opportunities and Issues of Recycling Treatments. *Journal of Environmental Management*. (264), 110500.
- National Renewable Energy Laboratory n.d. Abgerufen am 21.02.2022 von <https://www.nrel.gov/>
- Neef, C., Schmalz, T., Thielmann, A. (2021). Recycling von Lithium-Ionen-Batterien: und Herausforderungen für den Maschinen- und Anlagenbau Kurzstudie im Auftrag der IMPULS-Stiftung (Stiftung für den Maschinenbau, den Anlagenbau und die Informationstechnik) Recycling von Lithium-Ionen-Batterien: Chancen und Herausforderungen für den Maschinen- und Anlagenbau. Verfügbar unter: https://publica.fraunhofer.de/eprints/urn_nbn_de_0011-n-6434738.pdf
- Oberrheinkonferenz. (2020). Statistische Broschüre Oberrhein. Abgerufen von: https://www.oberrheinkonferenz.org/de/statistik/downloads.html?file=files/assets/ORK/docs_de/allgemein/broschueren/statistikbroschuere-oberrhein-2020.pdf&cid=2792
- Patenaude, J. (2014). Die Bewertung der sozialen Akzeptanz neuer Technologien: Lücken und Spannungen zwischen Wissenschaft und Regulierung. *BioéthiqueOnline*. Verfügbar unter: https://www.researchgate.net/publication/269573770_Assessing_the_Social_Acceptability_of_New_Technologies_Gaps_and_Tensions_Between_Science_and_Regulation
- Peters, E., Västfjäll, D., Slovic, P., Mertz, C.K., Mazzocco, K., & Dickert, S. (2006). Zahlenverständnis und Entscheidungsfindung. *Psychologische Wissenschaft*, 17, 407-413.

Ribon et al., 2018: Ribon B., Badariotti D. et Kahn R. 2018. Fondements des analyses de flux de matières et d'énergie et typologies d'applications pour la gouvernance des territoires et des organisations. Vertigo - la revue électronique en sciences de l'environnement, Volume 18 numéro 2. DOI: 10.4000/vertigo.20822

Regierungspräsidium Freiburg, n.d., Oberrhein. Abgerufen am 20. Dezember 2021 unter: <https://rp.baden-wuerttemberg.de/rpf/sgz-en/upper-rhine/>

Samsatl, S. , Samsatli, J.N (2019). Die Rolle von erneuerbarem Wasserstoff und Zwischenspeichern bei der Dekarbonisierung von Wärme - Umfassende Optimierung zukünftiger Wertschöpfungsketten für erneuerbare Energien. Applied Energy, (233-234). 854-893. <https://doi.org/10.1016/j.apenergy.2018.09.159>.

Spangenberg, J. (2011). Wissenschaft der Nachhaltigkeit: Ein Rückblick, eine Analyse und einige empirische Lehren. Environmental Conservation, 38(3), 275-287. doi:10.1017/S0376892911000270

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

Specht, M., Zuberbühler, U.; Wittstadt, U. (2004). Regenerativer Wasserstoff - Erzeugung, Nutzung und Syntheserohstoff. Stadermann, G. ; Forschungsverbund Sonnenenergie -FVS-: Wasserstoff und Brennstoffzellen-Energieforschung im Verbund : Jahrestagung des Forschungsverbunds Sonnenenergie, 25.-26.11.2004 in Berlin. Berlin: FVS, 2005 (Forschungsverbund Sonnenenergie. Themen 2004). S.33-40 Verfügbar unter: Regenerativer Wasserstoff - Erzeugung, Nutzung und Syntheserohstoff

Tarascon et al., 2021: Tarascon, J.-M. 2021. Batterien: Constituants, Évolution des recherches, Batterie 2030+. Le tout en 5 min. Webinar, 13. April. <https://www.concertation-acc-batteries.fr/compte-rendu-et-replay/7>.



SUMMARY REPORT

Feasibility Study Innovation Region Fessenheim
2021 – 2022

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The basic idea of the feasibility study is to identify viable transformation paths for the energy sector connected with a sustainable future oriented industry, incorporating relevant studies, science partners and stakeholders from society as well as industry/economy.

Barbara Koch

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01. Introduction

The need for sustainable development has dominated the environmental policy discourse in the 21st century making it an overarching policy paradigm (Komiyama & Takeuchi, 2006; Spangenberg, 2011). With the passage of time, the role of radical and systemic innovations has been at the forefront of achieving sustainable development goals (Boons et al., 2013).

The feasibility study “Innovation Region Fessenheim” originates from the similar ethos of sustainable innovations. The focus of the study is on developing a pilot innovation region based on innovative, new technologies in order to attain emission neutrality and sustainability in the energy system and to promote local value addition and job creation. Based on a bilateral understanding, the feasibility study will develop a role model for cross-border European regional development. The study proposes ideas for demonstration projects particularly in the fields of “Green Batteries”, “Green Hydrogen” and “Smart Grids” and sheds light on the interlinkages and co-benefits of their potential implementation (see Figure 1).

By making use of an interdisciplinary and praxis-oriented approach, the feasibility study aims to work with partners and stakeholders from science, business, politics, public administration and the civil society to advance the de-fossilization of the energy system and consequently the economy in the region. The project uses the competences found in the Upper Rhine Cluster for Sustainability Research (URCforSR), such as individual research institutes, Eucor - The European Campus, and TriRhenaTech to form an overarching coalition. The main focus and strength of the study is to bring together the broad scientific knowledge and expertise in the Upper Rhine valley with practical knowledge from industry and societal stakeholders. As a result of former tri-national studies (RES-TMO, Smart Meter, SumoRhine) and the *Projet de Territoire* studies, four important elements have been identified for the development of the innovation region:

1. The demonstration of new technological concepts related to sustainable energy innovation through regional Living Labs that may deliver tangible outputs to citizens in future
2. The connection between the region's existing scientific expertise and industrial investments through transformation and innovation hubs
3. The development of concepts for integrating the areas of training, further education and teaching to continue boosting the model region
4. The initiation of a discourse with the various communities in the region about the project's vision and concrete innovation pilots and to take their input into consideration

Together, the afore-mentioned elements constitute the pillars for the development of a cross border innovation region and contribute to the main idea of the feasibility study.

By incorporating relevant studies, science partners, and stakeholders from society and the economy, the feasibility study's main idea is to identify viable transformation fields for the innovation region by factoring into the equation the total regional primary energy consumption to induce a transformation towards a future oriented industry and energy market. Specifically, the study's vision is to establish:

- A cross-border European innovation region by connecting regional players from academia, the economy, and society
- A European role model (Living Lab) as an example for a societal and industrial transformation towards sustainability

With this intention, after analysing the regional assets of the Upper Rhine and the Fessenheim innovation region, development fields that fulfil the requirements of the political requests highlighted in the *Projet de Territoire* were identified. The political goals described in the *Projet de Territoire* are embedded in the European, national and regional objectives to attain sustainability and climate neutrality.

Along with the transformation goals towards sustainability and climate neutrality, the *Projet de Territoire* has postulated that generating technology innovation hubs in the region leads to:

- Future oriented employment
- Innovation industries
- Cross border education and training
- Citizen participation.

Linking the postulated goals of the *Projet de Territoire* and the regional assets of the Upper Rhine and the Fessenheim innovation region, the ideas for the development of pilots as best practice examples are based on four competence groups. Three competence groups are categorised as technological innovation hubs:

1. Innovation hub for green batteries and circular economy of batteries
2. Innovation hub for green hydrogen
3. Innovation hub for smart grids

Additionally, the fourth competence group, “territorial framework”, investigates the environmental, societal, regulative and economic frame conditions for the implementation of the three technological innovation hub competence groups (Figure 1).

CO₂-neutral energy and transportation concept

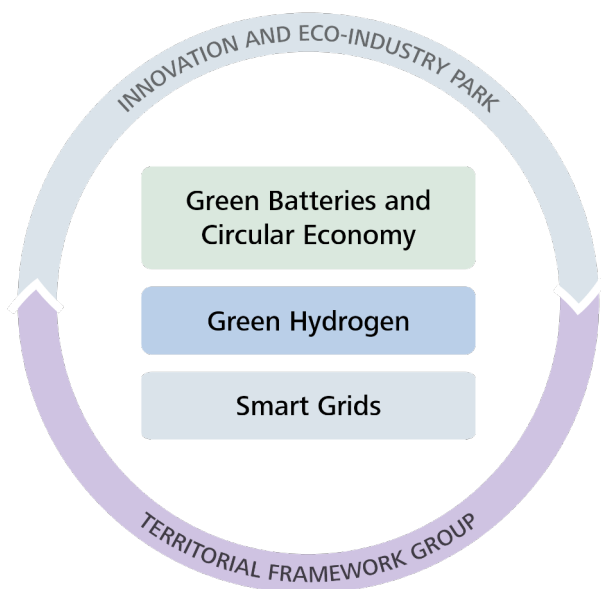


Figure 1. Innovation fields for the development of best practice examples embedded in territorial framework conditions and located in innovation and eco-industry parcs

Another key idea is that the selected technological innovation hubs are interrelated, correlated and need to be executed simultaneously for a successful and sustainable regional transformation. To elaborate more on the subject, the link between batteries and green hydrogen is of great importance for the overall regional transformation because they are complementary in terms of implementing a storage system for volatile renewable energy, stabilising the grid, and contributing to transport and industry processes and applications. They complement each other by varied temporality in storage capacity and the flexibility in the energy system (Specht et al., 2004). For example, in terms of industrial applications, batteries are more agile in their energy supply but not adapted to energy intensive processes while green hydrogen is especially efficient and energy saving in energy intensive industrial processes. On the other hand, in terms of transport, batteries could be relied on for passenger traffic, while green hydrogen might outperform batteries in heavy duty transport using ships and trains. In addition, the adaptation of the grid to accommodate renewables is necessary for increasing the energy supplied by renewable energy sources and can be supported by the innovative applications described in the battery and green hydrogen innovation hubs, because they can both contribute to a sufficient and timely electricity supply.

Keeping the above in mind, the following chapters elaborate on the local assets of the Fessenheim region and give an overview of the themes, research and recommendations of each of the competence groups to make the case for the full scale implementation of the proposed complementary pilot projects.

02. Regional and Local Assets For the Innovation Region Fessenheim

As mentioned in the introduction, the competence group themes are based on the political goals and regional assets of the Innovation Region Fessenheim. This chapter will provide an overview of the regional assets.

The innovation region Fessenheim is embedded in the Upper Rhine Region (Mandate Territory of the Upper Rhine Conference) a geographically diverse region at the border triangle of France, Switzerland and Germany. The Rhine is the region's main transport route and constitutes its natural border. The region is characterised by the Rhine valley which is enclosed by the mountainous regions of the Vosges in the west and the Black Forest in the east. On the southern edge are the foothills of the Jura in Switzerland. The region is inhabited by more than six million people (Jung et al., 2012) and has a strong economic performance (BIP 272 billion/year) (Regierungspräsidium Freiburg, n.d.). Directly connected to the Fessenheim area is a well-connected transport infrastructure comprising three European transport corridors, the well-built European gas pipelines, and the European high voltage electricity grid (EC DG Mobility and Transport n.d.).

The Upper Rhine region is suitable for becoming the innovation hub in the fields mentioned above for many reasons. First and foremost, the region presents a high economic potential manifested by its GDP of €272 billion/year, which is more than that of Finland and Ireland put together (Regierungspräsidium Freiburg, n.d.). In addition, the existing industrial infrastructure in the region promotes the development of small and medium enterprises (Interreg Upper Rhine, 2019). Therefore, because the cross-border industrial activities are strongly developed, cross-border joint investment projects can add a lot of value, according to a European study which estimated that the boost potential in border regions can attain a growing rate of 485 billion Euro if accompanied by severe cut-back of legal and administrative barriers (European Commission, 2017) which are responsible for a loss of 3% of the European BIP (European Commission, 2017). Aply, the focus of this feasibility study is barrier-free innovation hubs. In 2018, the Upper Rhine region had approximately 3.2 million jobs. 97,000 workers commuted to neighbouring countries, 61% of them from Alsace and 38% from Baden Baden. The number of cross-border commuters increased by 12% compared to 2008 (The Upper Rhine Conference, 2020)

According to the cross-border region study of the European Commission (EC) report 2017, the number of employees can be boosted by joint investments. In fact, only 2% of EU citizens cross national borders within the EU, but 66% of citizens along border regions regularly cross the national borders within their region (European Commission, 2017). The potential for the development of new working places in European cross-border regions was estimated by the European Commission Report published in

2017 to reach eight million. Therefore, border regions are important for complementary, horizontal European integration.

The Upper Rhine region's assets, that can contribute to the regional sustainable transformation and growth and to the added value for society and the economy, are the following:

First: The chemical and pharmaceutical industries are highly relevant in terms of employment generation and value creation. However, to remain globally competitive there is a strong need to transform this regional industry into a more energy efficient industry with less CO₂ emissions. For this end, the transfer of innovative technology to enterprises must be increased based on best practice examples.

Second: The Upper Rhine must not miss out on promising investments in the transport sector, the energy sector or on creating a circular economy. As an example, when it comes to the transport sector, the region has a large volume of traffic and trade; therefore, emission reductions in the transport sector could have a great impact and help attain climate neutrality. Moreover, the Upper Rhine region has strong ties to both the car industry and the relevant technology and innovation that support the transformation towards climate neutrality of the transport sector (including car manufacturing components). Keeping up with the latest climate neutral trends, is also of high relevance for establishing future oriented working places in the region.

Third: The Upper Rhine region has a central location in Europe and possesses many reliable connections and routes that allow for multimodal and efficient transport of goods. The regional transport infrastructure includes: the existing transport corridors Rhine-Alpine, Atlantic and Rhine-Danube that connect to the leading European sea harbours Rotterdam – Genoa – Marseille (Rhône shipping route) and the Danube harbours located farther down towards the Black Sea. Moreover, major train railways and highway infrastructure exist along the transport corridors, function also as a link between the shipping routes. The most important transport connections in the Upper Rhine are the north-south connections which provide excellent conditions for port loading and unloading as the harbour administration reports (Hafenverwaltung Kehl, 2015). Furthermore, important European gas pipelines and power lines are located within the area. These facilities are already ready for use and if needed, can be adapted for transporting green electricity or green hydrogen in the future from north to south or to the European high voltage grid in other directions.

Fourth: In the region, there is a high concentration of research and education institutions, including globally recognized institutes in the fields of energy, technology and sustainability. Universities and private enterprises, offering a great opportunity to create a solid network for innovation. Due to the high concentration of educational establishments, a large number of well-educated young people with the needed skills in all levels of training are continuously entering the job market. Therefore, the Upper Rhine region possesses ample human resources for a sustainable technological transformation. In addition, the fast track connections available for commuting between Austria (daily), France (daily), Switzerland (daily), Spain (weekly), Luxemburg (weekly), Belgium (weekly), Netherlands (weekly) and Italy (weekly), are attractive for young Europeans wanting to work part-time or more in the Upper Rhine region.

Fifth: The Aachen treaty includes experimental clauses, which can be used to demonstrate how a successful cross border integration (CBRIS) contributes to the added value of a joint innovation industry.

In addition to the regional assets discussed previously, the local assets in and around Fessenheim such as the availability of harbours, traffic infrastructure, industries and their factories indicate the high potential of the region to become a European role model for regional transformation towards sustainability.

However, the success of the implementation of the recommended pilots in the different innovation fields is based on two cornerstones: the viability of a business case for the first private stakeholders and visibility, public support and public acceptance. If all these requirements are met and political support is provided, the implementation of the recommended pilots for a sustainable CO₂-neutral economic region will be made possible.

03. Renewable Energy Potentials in the Upper Rhine Region

Over time, renewable energy resources have become important contributors to the total primary energy supply at the global scale (Gernaat et al., 2021). The availability of renewables becomes more and more a pre-condition for successful transformation through investments. The success of pilot implementation is therefore directly linked to the availability of green energy. Therefore a chapter is included in the report which estimates the technical potential for renewables in the Upper Rhine Region.

The European Parliament on its website defines renewable sources of energy as: wind power, solar power, hydroelectric power, ocean energy, geothermal energy, biomass and biofuels. In July 2021, the European Commission proposed increasing the proportion of renewable energy in the EU energy mix as part of its binding targets in the Renewable Energy Directive and the promotion of renewable fuels such as hydrogen (EUROPA - European Commission, 2021). In a study carried out within the Interreg Upper Rhine project “RES-TMO”, the technical potential for renewable energy generation in the Upper Rhine Region was investigated and the major results are included here because of their outstanding importance to the whole transformation process.

As far as the estimation of the renewable energy potential is concerned, it is important to start by defining what is meant by renewable energy (as defined above) and potentials. The potential hierarchy can be observed in the figure below with definitions according to Jäger et al. (2016). The potentials include: theoretical, geographic, technical, economic, and feasible ones. The investigations within the

RES-TMO project stop at the level of the technical potential as the last levels (economic & feasible) have to be calculated on a case-to-case basis. The technical potential takes into consideration the land-use, system and topographic constraints as well as the technological constraints of the renewable energy technologies (Lopez et al., 2012).

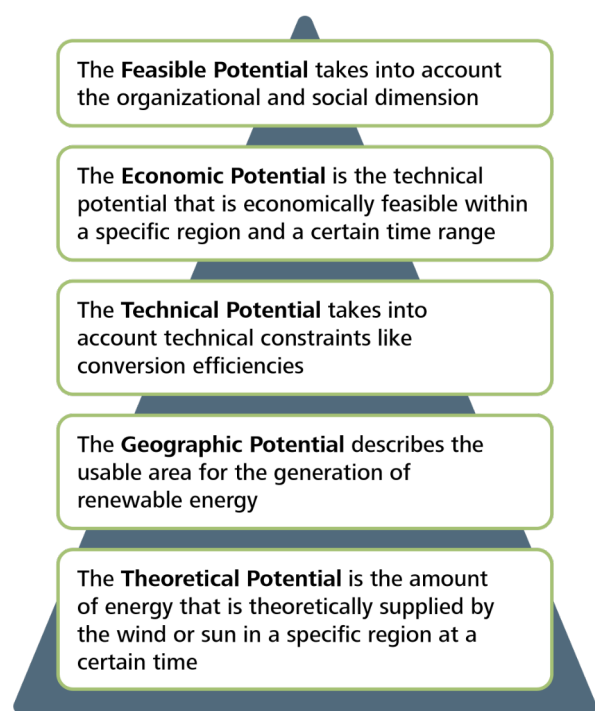


Figure 2: The Potential Hierarchy as defined by Jäger et al. (2016) and adapted in the RES-TMO Project

Major Findings

Wind: The results indicate that the technical potential for wind energy production in the Upper Rhine Region is 128 TWh per year. On a country level, wind technical potential is relatively higher in France and Germany than in Switzerland. The total annual energy demand in the Upper Rhine Region was estimated to be approximately 212,41 TWh/y, and half of it could be met by wind energy. However, it is important to recognize that economic and regulatory conditions, along with social acceptance of the technology, limit and reduce the technical potential of wind energy in the region and not more than 10% of the technical potential can realistically be expected.

Solar Photovoltaics (PV): The second important renewable energy source in the region is solar PV. In the RES-TMO study, the solar PV potential in the Upper Rhine was divided into two categories: roof-top PV and free-range PV. Free-range PV was again divided into two sub-categories that depend on land use: ground-mounted (GM)-PV and Agricultural (Agri)-PV.

1. **Rooftop PV:** The RES-TMO project estimated that the technical potential of rooftop PV is 52 TWh per year which can theoretically cover approximately 24% of the total energy demand. However, the total technical potential is limited by restrictions, like the load capacity of roofs, shadowing effects and protected monuments as well as the preparedness of citizens to invest in the installations. The societal acceptance for this renewable energy source is relatively high (Cousse, 2021). It would be a success if 40% to 50% of roofs could be covered by solar panels in the long run; however, this is only achievable under the best frame conditions.
2. **Free-range PV:** The technical potential for free-range PV is divided into two sub-categories: Agri-PV and GM-PV. Essentially, the difference between the two is that Agri-PV accounts for the dual use of arable land for both energy and food production. The estimated technical potential for free-range PV (159.5 TWh per year) is the largest, but could still be restricted due to environmental and societal aspects that could not be factored in. When it comes to the potential hierarchy, the economic and feasible potentials will be more limited than the technical potential. Finally, if 50% of the technical potential of solar energy is utilised as free-range PV, a significant contribution of nearly approximately 80 TWh per year to the total energy demand of the Upper Rhine region is possible.

Hydropower: Another renewable energy source investigated by the RES-TMO project is hydropower. The project concluded that hydropower's contribution of 13,6 TWh

per year is limited because the region's hydropower resources are already extensively used and almost exhausted as confirmed by experts on both sides of the Rhine.

Biomass: Biomass is used increasingly nowadays to substitute fossil fuels in the transport and the energy sectors. It has the advantage in comparison to fossil fuels, of regional availability in Europe and its ability to be stored. The latter is an advantage in comparison to the intermittent renewable energy sources like wind and solar. The RES-TMO project based their estimation on the Biomass Oui Project (Schumacher et al. (Eds.), 2017), which thoroughly investigated the same region's biomass potential. The estimated biomass potential of 5,2 TWh per year is rather limited.

Geothermal: Another source of renewable energy is geothermal energy. Geothermal energy sources can be differentiated into technologies utilising the shallow subsurface (10m to 100m depth) and methods exploiting the deep subsurface (1000s of metres depth) for energy extraction. Shallow geothermal energy is commonly used to supply heating or cooling energy, while deep geothermal energy can be employed for both electricity generation and space heating." (Miocic, 2021). The study conducted in the TMO (Trinationale Metropolregion Oberrhein) region, suggests that although there are already several ground source heat pumps (GSHPs) installed in the TMO region, there is still scope for many single-family homes in the region to be heated and cooled with GSHPs, in particular when combined with a future-proof low-energy renovation. Thus, increasing the share of GSHPs used in the TMO may enable a drastic reduction in carbon emissions related to space heating and cooling." (Miocic, 2021). The efficiency of deep geothermal wells is dependent on how deep hot fluids are encountered as well as the properties of the rocks the fluids are sourced from. Geologically, the TMO region has a high heat flow density which leads to high temperatures in the relatively shallow subsurface, and thus represents an ideal region for deep geothermal exploitation (Harlé et al., 2019). However, societal concerns about earthquake risks have to be seriously taken into consideration turning technical potentials into feasibility potentials.

An overview of the estimations of the energy demand and renewable energy sources' technical potential in the Upper Rhine Region is presented in table 2.

Table 2a: Estimated energy demand in the Upper Rhine Region

URR	Population in 2019*	Final Energy Demand in 2016 in MWh/capita**	Energy Demand in URR in MWh/yr***	Energy Demand in URR in TWh/yr***
Switzerland	1.507.718	49	73.878.182	73,88
Germany	2.858.606	26	74.323.756	74,32
France	1.888.480	34	64.208.320	64,21
Total	6.254.804		212.410.258	212,41

Table 2b: Technical potential of RES in the Upper Rhine Region

RE Source	Annual Potential (in TWh/yr)
Wind	128,0
Solar PV Rooftops	52,2
Solar PV Agro	91,5
Solar PV GM	68,0
Biomass	5,2
Hydropower	13,6

Conclusions

In conclusion, the technical potential of renewable energy sources in the Upper Rhine Region sums up to 358,5 TWh per year. Theoretically, the complete yearly energy demand of the Upper Rhine could be covered without even considering the geothermal potential.

The technical potential is limited to a large extent by factors such as land-use competition for food production, environmental impacts, landscape aspects, societal acceptance, economic framework conditions, regulations and

others. On a case-to-case basis, a more realistic potential estimation such as the economic as well as the feasible potential can be calculated as mentioned earlier. Nevertheless, the technical potential supports the development of better frame conditions and free spaces to effectively exploit the potentials through an integrative approach with strong participation of citizens and enterprises. Based on this knowledge of potentials for renewables in the Upper Rhine region, the pilot ideas within the defined fields for innovation hubs have been developed and their results are introduced in the next chapters.

04. Green Batteries with Circular Economy

The pilot plants necessary for establishing a circular economy of materials for lithium-ion batteries are presented below. Interconnections (see Figure 3) between these pilot plants, as well as connections to the pilot plants proposed by the other competence groups, are highlighted. Additionally, the specific advantages that support the respective pilot plants of the Fessenheim region are discussed.

Lithium-ion batteries play a crucial role in attaining a sustainable and carbon neutral energy sector. Since the lithium-ion battery is currently the most developed type of advanced battery technology available and it is widely used especially in electric vehicles (EV). By viewing the future prognosis of outdated batteries shown in Figure 4, it can be noted that the implementation of a circular economy for lithium-ion batteries should be prioritised when it comes to possible pilot plants in the Fessenheim region.

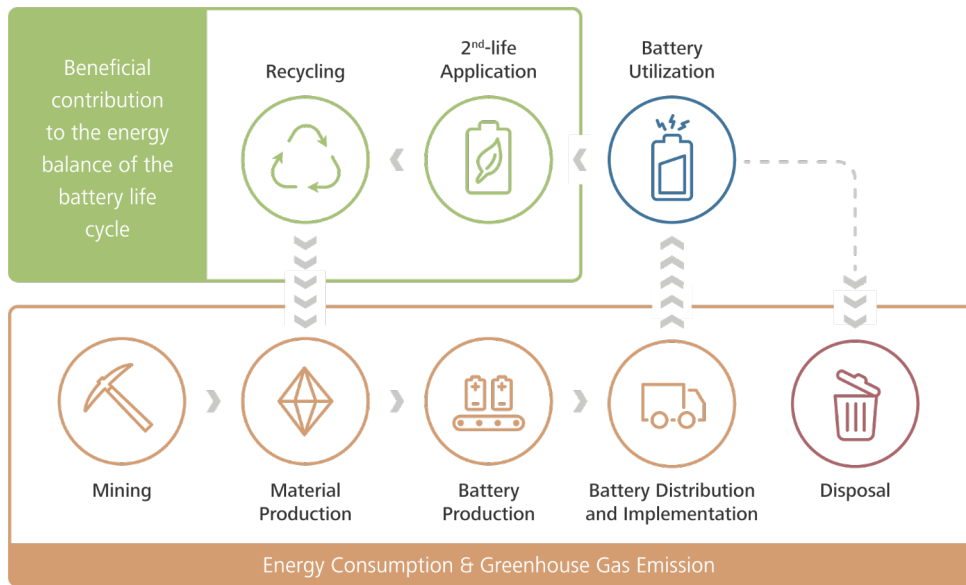


Figure 3: Lifecycle of a battery (Dühnen et al., 2020)

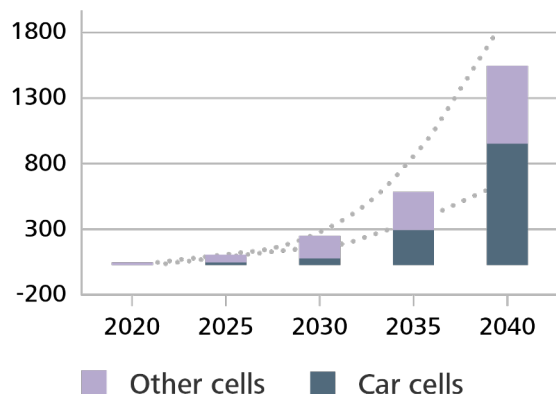


Figure 4: Prognose about the LIBs recycle flow in kt (high and low) till 2040 (Adapted from Neef et al., 2021)

¹The Circular Economy (CE) is a regenerative approach designed to reduce waste, and aimed at guaranteeing the eco-sustainability of post-use products (Mossali et al., 2020)

Figure 3 presents the lifecycle of a battery and focuses on the areas important for the planned circular economy implemented by the pilot plants and described later on.

To establish a circular economy as presented in Figure 3, the competence group (CG) Green Batteries suggests focusing on the following areas in Fessenheim and the Upper Rhine valley:

- Production of high-performance battery materials with a low environmental footprint using new and reused materials
- Qualification of used electric vehicle batteries for possible 2nd-life utilisation
- Installation of an electrical-energy storage with the integration of 2nd-life electric-vehicle batteries
- Development of an innovative dismantling and recycling plant for batteries at their end of life

Based on the aforementioned three main pilots are identified:

- **Pilot 1:** Infrastructure for second life utilisation of electric vehicle batteries comprising two pilot plants - a qualification centre for 2nd-life EV battery systems and a utility-scale hybrid electrical energy-storage (EES), complemented with 2nd life EV-batteries
- **Pilot 2:** Infrastructure for dismantling and recycling of batteries comprising two pilot plants - a facility for the dismantlement of batteries including diagnostics and a facility for the recycling of battery materials
- **Pilot 3:** A high performance battery material factory

It is important to note that only a holistic approach to all pilot plants (see recommendations, below) leads to the desired synergies along with the high economic as well as environmental benefits. The proposed facilities complement each other and offer significant business opportunities. For this reason, not implementing all of the proposed facilities in close proximity leads to reduced benefits for the region and hinders its competitiveness in the circular economy of batteries.

The suggested integrated pilot plants have many interconnections, mainly related to the exchange of materials and technological know-how. Furthermore, all of these facilities would strongly profit from the region's existing transport infrastructure, especially the ports along the Rhine, which offer a great advantage regarding the large-scale and economic transportation of ores or used batteries. The hybrid EES pilot project from the 2nd-life subgroup could be ideally connected to the grid infrastructure at the nuclear power-plant's old site and could also alternatively

make use of any grid infrastructure from other decommissioned power plants. The facilities suggested by the recycling subgroup and the battery materials subgroup have a high energy demand that needs to be provided by renewable energy sources whose substantial potential was evaluated by the RES-TMO project and discussed in section 3. Additionally, the suggested pilot plants will profit from the Fessenheim region's research institutes and universities as those can supply the required expertise concerning battery materials. The previous conditions make the region an ideal setting for collaborations with companies willing to invest in such facilities. Last but not the least, there are connections with the pilot plants proposed by the competence groups Green Hydrogen and Smart Grids and discussed in the following sections. One example is the rarely used but ever-present oxygen by-product obtained through hydrogen synthesis which is a necessary reagent for the manufacturing of battery materials. Another example is the hybrid EES envisioned by the 2nd-life subgroup which could be integrated into a smart grid.

On one hand, the Fessenheim region offers favourable conditions for the installation of pilot projects. On the other hand, secure jobs generated by the planned facilities mutually benefit the Fessenheim region. There is no alternative to a circular economy when it comes to battery technologies (mainly LIBs) because of the booming battery market which will lead to a mass of outdated batteries in the future. Environmental, societal and economic challenges demand a larger battery recycling infrastructure and offer less dependency on raw materials outside Europe as well as growth opportunities for the economy of the region. Figure 4 shows the expected development of the LiB recycle flow but an adequately planned capacity for battery second use and battery recycling hasn't yet been planned.

Recommendations

In order to establish a circular battery economy, it is crucial to locate the full processing line in the region. Therefore, establishing a qualification centre for 2nd-life EV battery systems and linking it with a utility-scale hybrid electrical energy storage complemented with second life batteries (pilot 1) while accounting for the logistics of collecting used batteries and distributing the second life battery packs to industrial users is recommended. The aforementioned pilot idea has already reached high technological readiness and the business model is clear. It is expected that this pilot can be established in the near future and it might be possible to use existing industrial buildings to implement the qualification centre.

As for pilot 2, establishing a pilot infrastructure as a test-bed for future industrial facilities focusing on dismantling and recycling batteries is recommended. Dismantling is a

process closely related to the qualification of batteries (pilot 1)) and should be done in an automated fashion (using robots). After the dismantling, the first step for the actual battery recycling process is based on a mechanical comminution process (mechanical shredding of the battery cells). In this shredding process, the so-called black mass is obtained, which is used for the extraction of the valuable elements (mainly cobalt and nickel). As a result of the recycling process, these elements are obtained in a form that allows their utilisation as starting materials for the production of new battery materials (pilot 3). The whole recycling process should include diagnostic units which are important for the recycled materials' reuse as raw materials. Although valuable and critical raw elements for reuse can be obtained from the recycling of lithium-ion batteries, a lot of challenges connected with new innovations have yet to be tackled. In fact, the battery advisory group of the California Environmental Protection Agency (CalEPA, n.d.) has stated that the establishment of demonstration projects, as suggested in pilot 2 for the recycling of lithium-ion batteries, to improve our knowledge on the performance (i.e. lifespan, degradation rate) and safety of the recycling processes add. These testbeds are urgently needed to increase public confidence, ensure the best use of materials, and test their economic feasibility. It is also recommended to establish both pilot infrastructures at the same time, to test the full recycling process in close proximity.

Battery recycling is closely linked to the idea of a battery material factory (pilot 3); therefore, the infrastructure for the development and production of new battery materials from recycled raw materials alone or together with new raw materials is recommended. The innovation of integrating recycled raw materials from old batteries in the production of new battery materials is an ongoing futuristic task and needs close cooperation between science and industry.

We recommend that these complementary pilot plants be implemented as an entity in order to optimise the benefits of the resulting synergies, mainly the exchange of materials (reduction of transport) and know-how (new innovations) (see figure 5).

It is important to note that building these facilities needs large investments. In effect, the industry needs to be convinced that cross-border joint investments in combination with EU based fundings under the Green Deal are a chance to obtain larger investment funds and to better overcome investment challenges. Installing the proposed pilot plants in the area of the Euro district Breisach - Biesheim - Fessenheim is strongly advised. In this proposed location, the port infrastructure supports tri-modal capacities for transport logistics. Finally, renewable energy can be harvested on both sides of the border for this infrastructure and there are many possible locations to implement the related infrastructures.

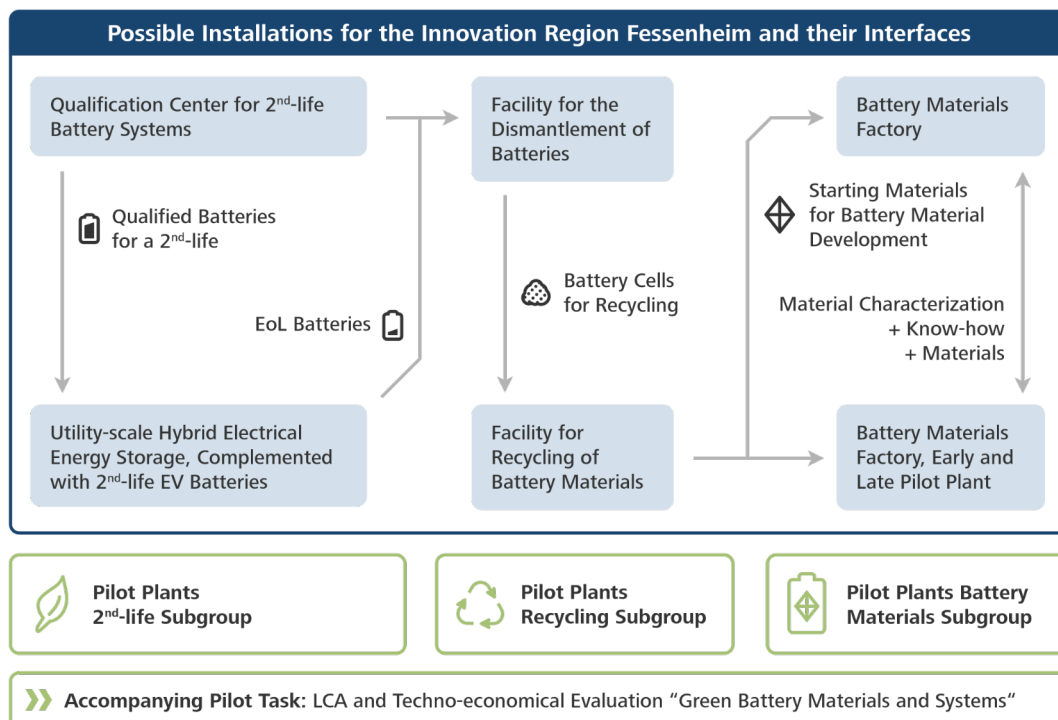


Figure 5: Main pilot scheme suggested by the battery competence group

05. Multi-Modal Hydrogen Hub Fessenheim

Implementing hydrogen as an energy carrier provides unique opportunities for the broader integration of renewable energy and an optimised use of resources along with the creation of future-oriented jobs. Its implementation ultimately ensures the region's development into a sustainable and forward-looking CO₂-neutral economic region. Hydrogen allows for the seasonal storage of renewable electricity and helps to build a more robust energy system by coupling the different sectors in a flexible and efficient way (Samsati & Samsati, 2019). In addition, several large companies which use hydrogen in their processes are located in the region around Chalampé and in the Basel area. Another key point is that the region is abundant with elements, projects and regional players which can collectively form the Multi-Modal Hydrogen Hub and cover the full value chain from production to distribution to usage.

These supporting conditions along with the region's diversity and complementarity were revealed by the "South Rhine H2 Summit" which was organised in November 2021 in Biesheim (Haut-Rhin) by the European Collectivity of Alsace. The study's results show that the industry demand for green hydrogen is considerably higher than in other sectors. Moreover, the currently conventionally produced hydrogen can be (relatively) easily replaced by green hydrogen.

So, it is suggested that the construction of the Multi-Modal Hydrogen Hub (see Figure 6) start by establishing large-scale capacities for electrolysis. The large-scale locally available green electricity will reduce the costs for green hydrogen production. This initial step will also showcase the benefits of using the hydroelectric power plants in operation in the area with solar PV as the hydroelectric power plants can be used at night and sunless days for electricity production.

Furthermore, import capacities for supplementary green hydrogen via the Rhine will be subsequently developed. The robust supply infrastructure and the availability of liquid hydrogen will turn the hub into a trade base for green energy especially when accompanied by the extension of the container-based transport into a multi-modal transport scheme and the combination of the regionally available transport infrastructure via water, roads and rails. In this case, fertile ground is created for more distributed applications of green hydrogen in the region, like establishing a fleet of green hydrogen trucks for heavy duty transport or the de-carbonisation of public transport with hydrogen driven buses and trains. Likewise, the increasingly distributed production and use of green hydrogen and the promotion of so-called hydrogen "prosumers" in the agricultural sector will exploit another regional asset by bringing hydrogen technologies closer to the general public and anchoring them in the region.

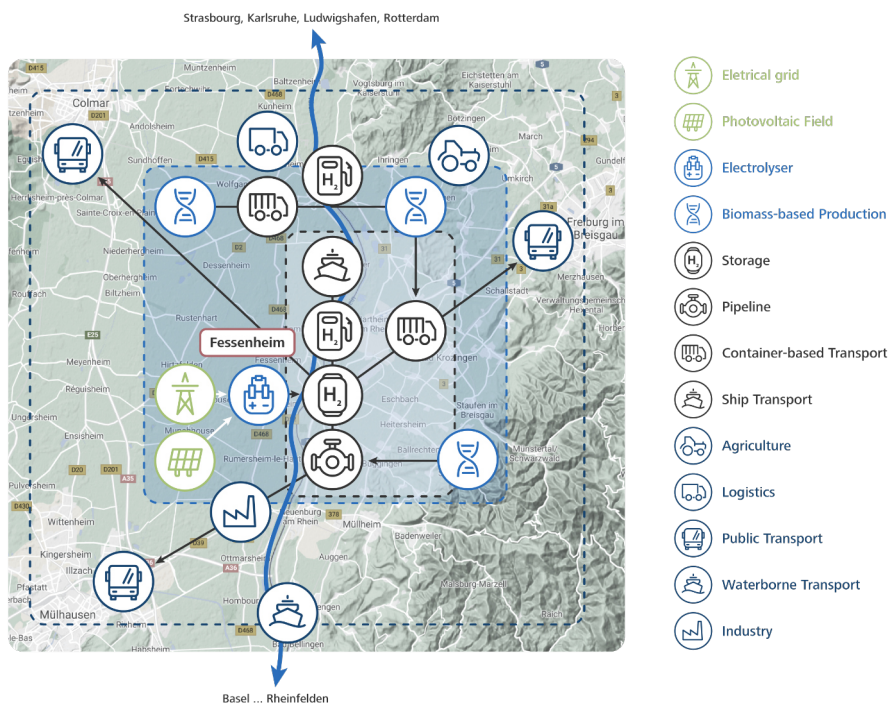


Figure 6: Main elements of the Multi-Modal Hydrogen Hub in the Fessenheim region

Based on the aforementioned reasons, a Multi-Modal Hydrogen Hub is recommended in order to explore the region-specific production and application possibilities for green hydrogen. So, the Multi-Modal Hydrogen Hub shall be based on the following four, complementary pilot projects, covering the key features of a functioning hydrogen energy system:

- **Pilot 1:** H2-A “Large scale industry supply with green hydrogen”
- **Pilot 2:** H2-B “Virtual Pipeline”
- **Pilot 3:** H2-C “Heavy Duty Transport”
- **Pilot 4:** H2-D “Distributed production and use in agriculture”

Recommendations

First, with the initial Pilot 1 H2-A, we recommend the installation and operation of a large-scale 200 MW electrolyser system located close to Ottmarsheim and the industry area of Chalampé. This location is proposed due to its proximity to the industrial area of Chalampé and the trimodal German-French traffic junction at Ottmarsheim (harbour, railway and highway). For an initial set-up of about 30 MW, it is proposed to use a small fraction of the electricity produced by the hydroelectric power plants of Ottmarsheim and Fessenheim (each providing 160 MW nominally) and to combine it with a floating solar PV system installed in the water basins of these power stations. Additional floating solar PV installations are proposed at a later phase on several artificial gravel lakes in the vicinity. The electrolyser system should be installed close by and connected via the existing hydrogen pipeline to the industrial area of Chalampé. The co-location with the Ottmarsheim power station is optimal because it will allow the dual advantage of using the existing hydrogen distribution infrastructure and supplying green hydrogen to the connected industry at a fast pace. Eventually, an extension of the local hydrogen distribution infrastructure with a parallel high pressure pipeline should be considered in order to enlarge the capacity of the existing hydrogen pipeline and improve the quality of supply by providing a pressure of up to 100 MPa, which is useful for several applications, in particular transport (link to Pilot Project H2-B and H2-C). The high pressure allows for smaller and intrinsically safe pipe cross sections and transforms the pipeline into an intermediate storage system.

Second, complementary supply with green hydrogen via a flexible import option is recommended with Pilot Project H2-B. The construction of long transfer pipelines typically comes at a huge expense; furthermore, such pipelines are inflexible, quite rigid structures. Therefore, the pilot con-

cept of a “virtual pipeline” comes into place. The Pilot Project H2-B proposes the container-based batch transport of hydrogen via the Rhine. Using the container solution, losses due to transfer between stationary and transport containers can be prevented and the seamless upgrading from high pressure gaseous hydrogen to a more dense liquid hydrogen (LH2) is made possible. Because container-based transport may be easily extended from shipping lanes to a multi-modal transport scheme via rail and road transport, it will open up distributed applications far from the bunkering sites established at the industry harbour of Ottmarsheim and/or Fessenheim shipping lanes and make hydrogen distribution more flexible, robust and economic. Additionally, the availability of cryogenic LH2 will catalyse further research, development and demonstration of innovative solutions, like using LH2 cooled superconductors for hybrid electrical and chemical energy transfer lines or storage systems. Via the virtual pipeline established on the Rhine, the Fessenheim region will be directly connected to Rotterdam, which is expected to become the central European landing site for LH2 from overseas. Moreover, import via the virtual pipeline will cheaply compensate for the potential green hydrogen supply gap left by local production. Given these points and with import and export capacities developed, the Fessenheim region will be able to coordinate with the different industrial regional demand sites located along and beyond the Rhine and become the cross-border trading base for green energy.

Third, the important transnational road infrastructure connecting Northern Switzerland, the Grand-Est in France with German South-West has led many transport companies to operate branches in this area. To reduce the considerable CO₂ footprint of the regional road transport, it is recommended with Pilot Project H2-C to establish an on-demand service that offers green hydrogen-based transport capacities to companies. Inspired by the business model of the Suisse-based Hyundai Hydrogen Mobility, a service sector company will purchase and operate a fleet of hydrogen trucks (20-30 initially) and build and operate the required fueling infrastructure. Focusing this hydrogen related business in one service sector company will, on one side, help in negotiating best possible conditions (taxation, hydrogen pricing, ...) and on the other side sell economically attractive packages to customers. Correspondingly, a state-of-the-art, LH2 based fueling station (initial daily dispensing capacity of 1 t, finally 5 t) shall be constructed in the area Ottmarsheim. The station will be characterised by a modular design and shall consist of an independent, commercially operated research and development section. The commercial section will reliably fuel the fleet of trucks and provide sufficient capacity for smaller hydrogen bus fleets operated in Mulhouse and/or Freiburg and the research section will offer flexible interfaces and infrastructure for developing further heavy duty

fuelling protocols and for testing critical components, like heat exchangers and metering devices.

Fourth, the implementation of agro-photovoltaic (agro-PV) for local green hydrogen production is recommended with Pilot Project H2-D “Distributed Production and Use in Agriculture”. The use of agri-PV on farmland creates direct advantages for the farmers: Besides the extra income generated for the farmers, agri-PV provides protection for the plants against direct sun exposure and also during storms and hail (Fraunhofer ISE, 2020). In addition to using the electricity generated by solar PV and hydro, it is recommended to further test and develop the use of biomass for local production of hydrogen at a few prototypical locations. In the context of renewable hydrogen production, valorising biomass is a promising approach, in particular when non-valorised agricultural bio-waste can be

used. Additionally, the use of hydrogen in agriculture, mainly in agricultural machines with converted fuel flexible combustion engines and in combined heat and power units using high temperature fuel cells, shall be demonstrated. As can be seen, hydrogen offers new possibilities for the business model of agricultural co-operatives as fuel traders.

As shown above, the pilot projects are complementary as they address different production and application fields, highlight different technologies which are mature enough for scheduled implementation, and leave sufficient potential for further research and innovation. Although the projects could, in principle, be established independently, the overall system will greatly benefit from fully implementing them together and in the suggested sequence.

06. Smart Grids

Worldwide, and in the hope that they will become the norm for future electrical networks, smart grids, as intelligent electrical networks, are being developed because they are technologically advanced and equipped to optimise the production and consumption of electricity. The advantages of smart grids are many: for one, they can integrate new information and communication technologies such as connected objects, and as a result, they are capable of transmitting real-time information about electricity use and consumption to network operators (producers, distributors and consumers) (Butt et al., 2021). By providing real time information about energy flow, smart grids allow network operators to check, control, analyse and optimise energy consumption. The objective of smart grids is to use this collected information for adjusting the flow of electricity and, in turn, guaranteeing more energy efficient networks. Moreover, smart grids ensure the balance between supply and demand and inhibit the overheating of networks. Finally, smart grids can help to bridge the gap in the transition of energy resources from fossil fuels to renewables (Butt et al., 2021).

Generally speaking, both hydrogen technologies and green batteries, the subject matter of the other two competence groups, are completely dependent on smart grids for real time analysis of electricity consumption. Moreover, smart grids allow for the real-time optimisation of energy use, the reduction of energy loss, and the optimisation of the integration of battery storage capacities into the grid for more stabilisation. It is worth noting here that smart grids are fully adapted for renewable energy technologies as they can be adjusted at any time by integrating different renewable energy sources without compromising on efficiency, and they implicitly help in reducing carbon emissions. It is important to realise that intelligent

electricity management is one key for the successful transformation of the energy market (Bayindir et al. 2016).

The goal of the smart grid competence group is to map the existing regional transnational transmission system and collect information on the potential for renewable energy and its link to scenario development for the regional energy grids. Additionally, the goal is to study the potential of demand-side management, and to this end, it is imperative to identify possible weak points in terms of energy availability. Ideas for updating the electricity network connection concept between France and Germany and for displaying the expansion possibilities of the transmission grids is another focus of this group. Implementing such concepts allows the comparison of the technical alternatives available for grid and connector enhancements and supports the expansion towards more renewables. The development of discrete concepts also develops better ideas for optimising the transmission capacity of existing overhead line routes and analysis of the requirements for system security in renewable energy generation plants. One of the main challenges in the cross-border concept is to integrate the fluctuating electricity generation from renewables in the transnational electricity network. Thus, the goal is to design and operate an electricity transmission grid which is both flexible and adapted to different electricity generation plants. For the cross-border innovation concept for the Fessenheim territory, the goal is to design and operate the electricity transmission grid and adjust to the diverse electricity generation plants as well as the demands for more flexibility in the overall system.

The competence group’s analysis showed technical challenges like diverse energy use, security and usage of the electrical network, and the grid integration of e-mobility

and further storage capacity. These challenges also include the economic and societal aspects, like suitable economic models, social acceptability, and legal and security constraints.

For a better understanding of the regional challenges, the competence group organised two working seminars in July 2021 and linked the results to further inputs from science, industry and communities. The outcome of the seminars was narrowed down to objectives, further described in the text below, which guided the development of the pilot ideas. Consequently, it became clear that for the advancement of smart grid applications, the existing cross border network needs to be mapped out in order to identify potential weaknesses related to increasing proportions of renewables in the grid specifically regarding the connectors and electricity loads of the different national grid systems for medium and low voltage levels. Firstly, power grid engineering for physically up-grading the existing regional electricity grid is needed. Secondly, the establishment of testbeds for smaller neighbourhood units, like industrial parks or housing areas is also needed to fundamentally understand smart grid functionality by integrating storage capacities like stationary batteries or e-cars in order to learn about smart grid management challenges. Finally, the functionality and impact of smart grid systems on grid stabilisation and how to efficiently manage energy has to be tested as a meta-demonstrator within a cross-border situation, as the EcoRhena park may provide.

In the Upper Rhine area, the established industrial players ranging from energy producers to consumer industries (energy management, chemicals, automotive, etc.) and the existing engineering services are assets for the development of smart grid pilot projects. In addition, the required technical and scientific skills to implement the pilot projects are available in the region. Notably, another asset that supports the pilot projects is the commitment of local authorities and many companies to strategies for modifying industrial sites or neighbourhoods in order to reduce their carbon impact or even to achieve the ISO 50 001 (Energy management) certification.

To map out all the challenges and scopes of the smart grid innovation in the Upper Rhine, region, three pilots are proposed:

- **Pilot 1:** Establishing twin quarters, sustainable quarters between Mulhouse - Karlsruhe and cross-border meta demonstrator pilots for smarter management of renewables
- **Pilot 2:** Integrating electrical charging stations for e-mobility into the grid in the neighbourhood
- **Pilot 3:** Mapping of the regional grid situation and modelling future scenarios for the reinforcement of the regional grids to exchange volatile electricity on different voltage levels

Recommendations

The Smart Grids competence group recommends the installation of a smart grid system (Figure 7) in two neighbourhoods (Pilot 1) in France and Germany, as testbeds for smart grid management scopes like controlled and efficient electricity consumption on demand. The idea is to integrate smart grid systems in neighbourhoods in Mulhouse and Karlsruhe. The location is selected due to communal level openness to building such a pilot: in Karlsruhe, the implementation of the smart grid neighbourhood has already started, while the commune of Mulhouse is willing to invest in such an idea. The transfer of the gained know-how from the smart grid systems tested in the two city neighbourhoods to the planned implementation of the French-German innovation Parc EcoRhena, as an example for a cross-border meta-demonstrator is recommended. With this pilot the following goals will be achieved: a demonstration of how smart grids support the reduction of energy consumption, the integration and intelligent storage of renewable energy, the coupling of electricity sources, heat and cold management, and the creation of exportable models.

The group recommends testing the integration of e-mobility batteries into the smart grid system along with the implementation of the smart grid neighbourhoods (pilot 2) in an effort to gain knowledge on how this integration can enhance electricity grid management and how technical, economic, and societal barriers can be solved. The goals of this pilot are to improve the understanding of how to optimise the charging station network of a district and the coupling between the charging load network and the distribution network with the aim of reducing power peaks with e-mobility battery storage use, achieving the best profile and usage models, supporting the cross-border standardisation of charging networks. To this end, e-mobility charging stations for cars and bikes need to be included in the design of the smart grid neighbourhoods. It is suggested to start with industrial neighbourhoods by establishing electrical charging stations as test-beds for smart grid applications. As an outcome, it could show how e-mobility charging stations integrated in a smart grid can help save energy and optimise energy distribution in terms of availability as well as accessibility.

Another recommendation is to map out (Pilot 3) the existing regional electricity grid and analyse its weaknesses for optimal cross border electricity exchange as well as study its ability to stabilise under volatile electricity production. The goals of this pilot are based on European Union Energy Policy, which include stabilising the grid by keeping the frequency at 50Hz, optimising and decarbonizing the energy mix, and integrating the local grids with the transnational grid. The capacities of the existing networks and load profile simulations for the different scenarios of renewable installations provided by the RES-TMO study should be part of this pilot.

Incidentally, the smart grid competence group has not taken into consideration the gas pipeline energy grid because it wasn't the group's focus but recommends that this factor be investigated as a next step to ensure an integrated energy transformation.

Finally, each of these pilots needs substantial resources and the participation of network operators as well as communities and industry.

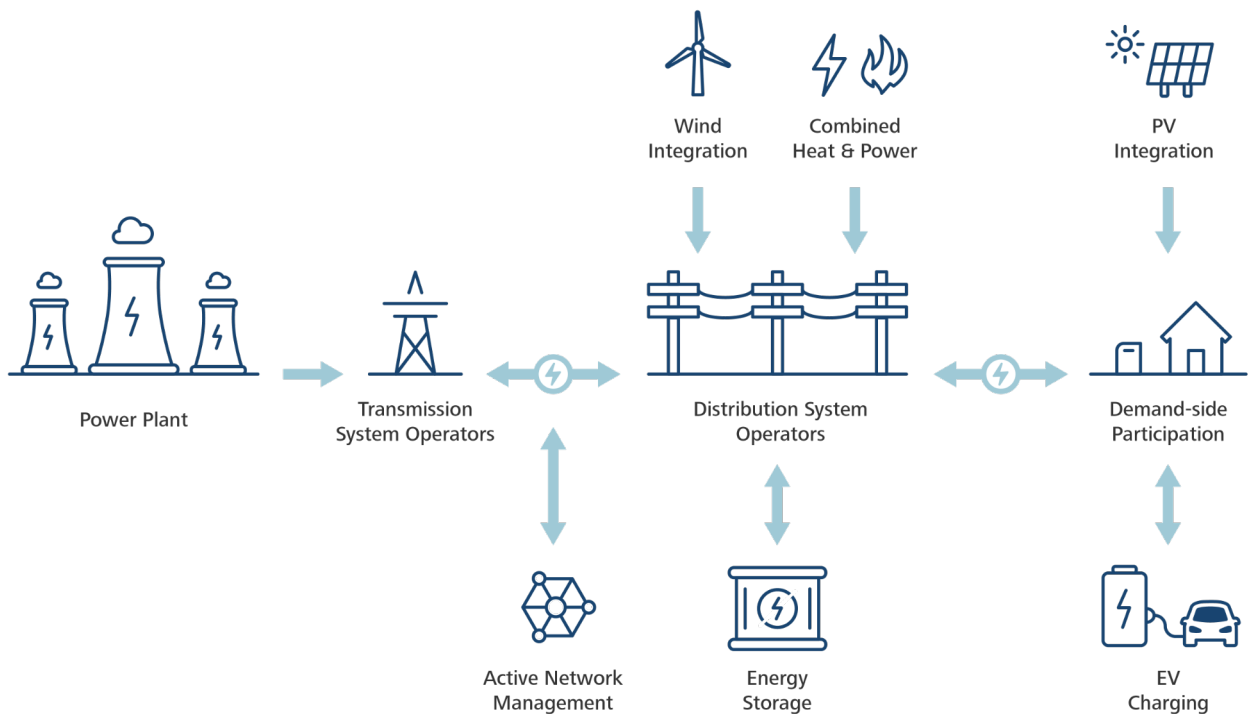


Figure 7: A possible testbed for a smart grid system in the quartier pilots

07. Territorial Framework

Innovative ideas are always prone to technological challenges and although cross-border scientific expertise in the Upper Rhine region is an asset for tackling those challenges, the main challenge left to overcome is the territorial one. The territory is very complex, and its complexity is increased by its transnational nature. Therefore, a framework of multiple dimensions in which the overall project has to be adopted is required.

To address these issues, the Territorial Framework competence group is a multidisciplinary Franco-German research group that relies on four thematic areas: social acceptability, environmental impact, territorial metabolism, and legal framework. Together, they cumulatively define the frame conditions of the Innovation Region Fessenheim territory. This competence group aims to support the concrete ideas developed in the other three feasibility study competence groups (Figure 8). Its objective is to provide a comprehensive picture of all the territorial aspects that could impact the project as a whole. The main findings are summarised in the following sections along with potential recommendations for action.

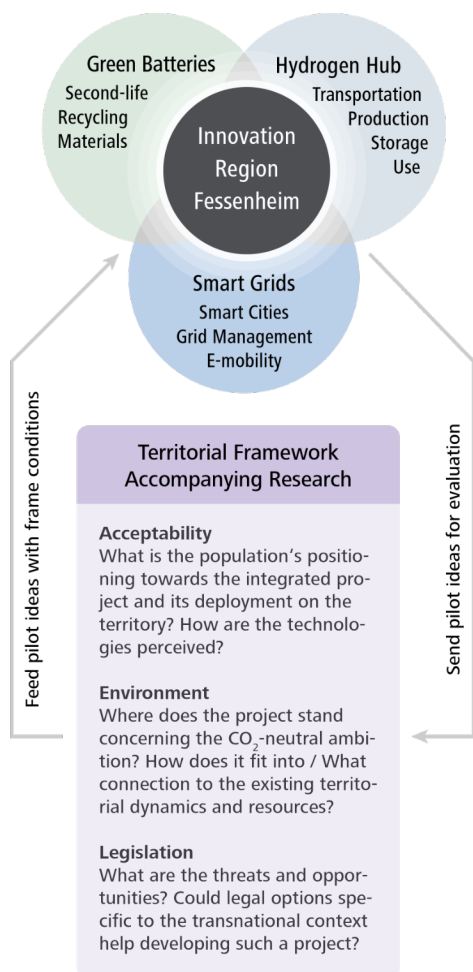


Figure 8: The Interconnection of the Territorial Framework group and the other competence groups.

Recommendations

► Social acceptability

Social acceptability of new innovations is crucial (Pate-naude, 2014). Societal needs, perceptions, and possible changes as well as ethical questions have to be taken into account. This competence group's research has produced the following results: green technologies are generally supported by the public and hydrogen appears to be the most acceptable technology followed by Green Batteries and then Smart Grids. A closer look into the different parameters reveals that objective knowledge has little to do with the level of acceptability and that trust [in various stakeholders] has a modest but real effect. The two most promising identified levers with positive impact appear to be the image conveyed (affect) and the associated benefits as both are positively correlated to the level of acceptability. In this regard, Hydrogen, in addition to being the most acceptable technology, conveys the most positive image and presents the best benefit-cost ratio compared to the other two.

Therefore, we recommend careful communication. The more positive the image (positive affect), the more likely it is for the project to be considered acceptable. The same concept applies to the benefits: the more the project is perceived as a source of benefits, the more likely it is to be considered acceptable. The effect is even stronger for the associated environmental benefits. Communication is key in building the image that will then be associated with the technology/project. Accordingly, the elements of communication on a project must be carefully designed to support this goal (Bostrom et al., 2018; Hoffrage & Garcia-Retamero, 2018; Peters et al., 2006).

On the other hand, acceptability also depends on the way the deployment of the project is intended in the territory. Another recommendation would be to involve the local population early on – starting from the project idea to its concrete development. The best way to go about this would be transparency between the promoter and the local population and consultation in the project development. Co-construction of the project is thus another interesting lever to explore.

► Environmental Impact

For the innovative projects, the green transformation of a territory entails the lowest impact on the environment (Söderholm, 2020). Not all individual pilot projects could possibly be evaluated during the timeframe of this feasibility study; for this reason, the choice was made to mainly focus on the impact assessment of the different possible scenarios for lithium-ion battery (LIB) recycling and the different existing hydrogen production means.

LIB recycling is still at its early stages but serves two ultimate goals: to limit battery disposal in landfills and lower the pressure on scarce resources (Harper et al., 2019). Four recycling scenarios were studied, each consisting of a specific combination of elementary processes. While data regarding LIB recycling processes is still sparse, the impact assessment highlighted one scenario as the most different efficiencies for recycling processes from an environmental point of view. Moreover, there is still scope for optimising the recycling processes and further reducing their environmental impacts (using less polluting chemicals). It is also interesting to note that other innovative technologies are worth considering as they could provide a shorter loop in the circular economy model. For instance, direct regeneration would allow for the refurbishing of batteries instead of producing new batteries out of recovered materials (Li et al., 2017; Fan et al., 2021). "LEGO"-type batteries that would significantly ease the dismantling during the recycling process are also being developed (Tarascon et al., 2021). Both previously mentioned technologies would result in even lower environmental impacts.

As far as hydrogen is concerned, several production means have been evaluated. The study showed that high-temperature electrolysis is indeed the best compromise from an environmental standpoint, especially if the infrastructure is supplied by an on-site network of steam. Producing hydrogen by electrolysis supports the overall ambition of reducing greenhouse gas emissions and moving towards carbon neutrality.

► Territorial Metabolism

A territory is a living entity whose metabolism can be studied in order to analyse the mobilised resources and question the territorial anchoring of a project (Ribon et al., 2018). The selection of relevant indicators makes it possible to measure the potential connection to existing territorial dynamics and identify preferential implantation zones. Building on the existing industrial fabric and creating synergies through sector coupling constitutes a win-win strategy that, in the long run, will not only provide alternative and decarbonized energy sources but will also defossilize the production methods of existing industries (Ribon et al., 2018).

The Green Batteries project is based upon the fast-growing market of e-mobility. The circular economy approach is essential in this respect and offers interesting perspectives for 2nd life and recycling of batteries at their end-of-life. The size of the pilot meets the present demand of the Upper-Rhine (1 ton of car batteries per day); however, fast-growing regional demand should bring this number up to 250 tons per day in the long run. Additionally, the plant's installation site should account for the technologi-

cal developments in battery recycling that might call for extra space for experimentation. The different technologies included in the project have varying levels of technological readiness and distinct timelines. While this factor might lead to potential synergies, interferences or dependencies could appear and need to be accounted for. Some technologies might require political and industrial partners beyond the Upper Rhine. Furthermore, the Upper Rhine region has deposits of minerals that are important for batteries and we would recommend (re-)exploiting these deposits of primary resources, particularly those of lithium and nickel.

The Hydrogen project can benefit from a few synergy potentials on the territory and could be implemented on several sites to develop a hydrogen ecosystem. However, the main constraint resides in the locally limited electricity production capacities, which could hinder the hydrogen production capacity mainly based on electrolysis. Using biomass resources to produce hydrogen is an interesting alternative which is compliant with territory resources and is worth being further pursued despite the fact that it is less mature than electrolysis. It also applies to other innovative production means (such as biogas, thermolysis, thermo-cracking) that are currently being developed and would reduce pressure on local electricity production capacities.

The Smart Grid project mostly relies on energy optimisation. "Energy sobriety" should also be underlined for smart grid effectiveness as it is probably the most important approach to build a resilient and climate neutral electrical network.

On a more general level, the rapid deployment of these projects seems to require: (i) a shared consensus of public and private stakeholders concerned and/or involved in the sector development, (ii) significant and explicit public support to limit the additional costs associated with emerging technologies, (iii) greater private stakeholder participation particularly in sharing information which is crucial for a better understanding of current and potential needs in order to develop the appropriate facilities, and (iv) a more explicit coordination with public policies at different territorial levels and with the surrounding territories.

► Legal Framework

The transformation of Fessenheim into a sustainable and innovative region raises legal issues linked to the existence of two, French and German, legislative systems across the border from each other. There are innovative solutions within these legislations; however, they need to be identified and applied in order to develop this project.

Cross-border cooperation could be the key to developing an attractive legal framework that would favour the con-

cretization of the project. If legal obstacles were to be identified for the envisioned cross-border coupling of green technologies or the implementation of specific facilities etc., cross-border cooperation could act as a legal tool that enables territories facing the same problems to experiment with and develop solutions together. Existing French legal options for innovative projects could be applied and possibly extended to Germany and vice-versa or new-for-both solutions could be implemented.

As an illustration, in the case of hydrogen, in comparison to the German legal framework, the French ecosystem appears to be safe and well-developed given that hydrogen is at the core of the French national and regional energy transition strategies (Langstädtler, 2021; Loi 2019-1147, 2019). Currently, the French legal framework is well-designed to develop pilot projects and to foster innovative ones (Code de l'Énergie - Livre VIII; Ordonnance n°2021-167, 2021). These innovations allow for possible legal derogations such as regulatory sandboxes to tackle possible legal obstacles that may arise, if eligible. The legal obstacles only imply a legal derogation from French law. If the need arises, an interesting solution for a cross-border project facing a legal obstacle could be to apply French rules which currently provide a better legal framework.

As far as batteries are concerned, the installation of a production unit requires an authorization in both legislative systems because of environmental concerns (n.d BIM-

SchG; n.d Code de l'environnement). This long and expensive procedure has to be taken into account before any concrete actions. Moreover, as opposed to Germany, no specific regulation exists concerning the storage of batteries under French law which constitutes a serious legal risk for battery recycling. Because Lithium is considered a dangerous product, it requires appropriate storage means and regulated transport.

Cross-border projects can benefit from a favourable European context (Clean energy for all Europeans package, 2019), so specific mechanisms for cross-border cooperation can apply. The Innovation Region Fessenheim can be considered as a bilateral innovative zone along the Rhine. Such a development is promoted by EU energy law (EUR-Lex energy, n.d.) and could make use of the derogation clause existing in the Aachen Treaty (Aachen Treaty - art. 13, 2019). Nevertheless, there is a limit to the possibility of applying a derogation and to avoid any normative dumping: the derogation must strictly comply with stringent environmental and social protection rules. The derogation clause of the Aachen Treaty also reflects the political will of both French and German states. In essence, reference must be made to the constitutional framework of the Member States as an imperative legal basis.

For the most part, the technical pilot projects can be used to identify legal and regulatory issues and barriers and to develop new legal and regulatory approaches - also on a European level - that are needed to upscale the technical solutions in a sustainable way.

08. Conclusion

The feasibility study has demonstrated that the Innovation Region Fessenheim is endowed with a number of assets (see Chapter 2) that could help it develop into a European cross border regional innovation system (CBRIS). In order to effectively use the proposed ideas for its development, the selected pilots need to be further elaborated on to concretize and clarify the ideas proposed and to construct for each one discrete implementation plans. For more detailed planning of the pilots or a selection of pilots, a consortium needs to be established with communal and European level stakeholders and industrial partners that possess scientific and administrative knowhow as well as legal competences. The selected pilots from different fields can demonstrate how the transformation towards sustainability is linked with the different technological innovation fields. For example, the generation of renewables is on one hand linked with the capacity of producing green hydrogen through electricity and, on the other, with smart grid systems to achieve optimal and timely electricity distribution with minimal losses. Equally important is the link between the stabilisation of the electricity grid and battery storage capacity as well as the link be-

tween battery storage and the need to recycle batteries for protecting the environment/climate and lessening the dependency on imported raw materials. Keeping the interdependencies in mind, a holistic approach of the interlinked pilots and their implementation in a region is essential to learning about the overall transformation process towards sustainability. Choosing the Upper Rhine region with its energy intensive industry clusters around Basel, Chalampé and Karlsruhe is an optimal way to demonstrate the benefits of regional cross-border innovation hubs towards more sustainability. Furthermore, it provides the chance to demonstrate, after the decommissioning of a nuclear plant (Fessenheim), how a cross-border region can be transformed into a prospering future-oriented innovation region within a relatively short time frame by joining the resources of both sides of the border. Above all, decreasing dependence on fossil and nuclear energy sources is symbolic for an area that previously hosted a nuclear plant on its grounds and especially for its citizens who lived in the vicinity of this plant and feel strongly about the issue. Besides, the benefits of cross-border hubs are many: overcoming administrative and legal barriers,

providing regional expertise that transcend national borders, and accelerating knowledge transfer between companies, societies and science organisations. Cross-border hubs increase cross-border flexibility for employees and multiply the resources for joint investments. Likewise, cross-border hubs advance intercultural understanding, join political visions, and strengthen by joint activities Europe's position in the world. A number of economists have even proved that value addition in cross-border hubs is significantly large (European Commission, 2017).

The Feasibility Study Innovation Region Fessenheim outlines preliminary possible pilot projects developed based on the identified regional strengths. The most feasible option is to implement these pilots in the same region as they can not only provide best practice examples of how an innovative transformation towards sustainability is put into action but can also demonstrate how nations on both sides of a border can benefit from cross-border joint activities. As a matter of fact, feedback provided by industry partners during several workshops confirmed that the proposed pilot projects are in line with their future plans. In the workshops, the partners also highlighted the pressure for a timely implementation of such pilots in order to gain the know-how and to scale-up for industrial facilities. According to a statement by Frans Timmermans, Executive Vice-President for the European Green Deal (2022)²: "The green transition will free us from our dependence on energy- and other resource imports. The circular economy more specifically will allow us to reduce our demand for primary resources, and use a lot less energy for our production and consumption". All the proposed pilots in the feasibility study comply with this statement and help to achieve this demand. Moreover, all pilots can be further investigated by the reader and are described in the form of a pilot sheet in the folder attached to this document. The pilot sheets will provide a basis for the concretisation of the pilot ideas. Finally, the pilots' implementation requires large investments which must be mainly secured as start-up funds and through public funds from a European to a regional level that can be used for refining and detailing the plans. Mixed public-private partnerships could provide the investments required for the pilot infrastructures.

For the acceleration of the above mentioned process, the next steps need to be implemented in a timely manner as per statements of industry members:

1. Formation of a management group to coordinate and administer activities (including public relations) for the innovation region with the goal of pilot implementation
2. Concretization of the pilot ideas by detailing the implementation requests, like the compilation of interested consortia members from science and industry, administrations, and society stakeholders for each pilot
3. Elaboration of the pilot's details and execution plans.
4. Formation of a steering group for all decision levels related to politics, industry, and societal as well as regional stakeholders
5. Formation of a territorial framework group to accompany the implementation planning related to environmental, societal, and regulative matters
6. Implementation of investor approach activities and an investment plan for companies and public and private investors
7. Determination of a start date for the pilots along with the public relation activities

In conclusion, it is imperative that the above mentioned steps be executed within a tight time frame. As mentioned previously, feedback from the workshops with industry members has indicated that time is the essence for taking the lead in the innovation field and creating an impact in this decade.

²<https://presidence-francaise.consilium.europa.eu/en/news/circular-economy-stakeholder-conference-the-eu-reaffirms-its-ambition-3-03/>

References

- Aachen Treaty (2019). Traité entre la République française et la République fédérale d'Allemagne sur la coopération et l'intégration franco-allemandes. Available at: https://www.diplomatie.gouv.fr/IMG/pdf/traite.aix-la-chapelle.22.01.2019_cle8d3c8e.pdf
- Bayindir,R., Colak, I., Fulli, G., Demirtas, K. (2016). Smart grid technologies and applications. *Renewable and Sustainable Energy Reviews*. (66),499-516.
- BlmSchG . n.d. Bundes-Immissions-Schutz-Gesetz Available at: BlmSchG - nichtamtliches Inhaltsverzeichnis
- Bostrom, A, Böhm, G., O'Connor, R.E. (2018). Communicating risk: Principles and Challenges. In M. Raue, E. Lerner, & B. Streicher (Eds.), *Psychological Perspectives on Risk and Risk Analysis: Theory, Models, and Applications*. (251-278). Springer.
- Butt, O.M., Zulqarnain, M., Butt, M.T. (2021). Recent advancement in smart grid technology: Future prospects in the electrical power network. *Ain Shams Engineering Journal*, (12) 1. 687-695.
- CalEPA n.d. Lithium-ion Car Battery Recycling Advisory Group. Available at: <https://calepa.ca.gov/lithium-ion-car-battery-recycling-advisory-group/>
- Clean energy for all Europeans package, (2019). Available at: https://energy.ec.europa.eu/topics/energy-strategy/clean-energy-all-europeans-package_en
- Code de l'environnement. n.d. Available at: Code de l'environnement - Légifrance
- Code de l'Énergie - Livre VIII; Ordonnance n°2021-167 (2021). Ordonnance n° 2021-167 du 17 février 2021 relative à l'hydrogène. Available at: <https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000043148001>
- Cousse, J. (2021). Still in love with solar energy? Installation size, affect, and the social acceptance of renewable energy technologies, *Renewable and Sustainable Energy Reviews*, (145), 111107.
- Dühnen, S.,Betz, J., Kolek, M., Schmuch, R., Winter, M., Placke, T. (2020). Toward Green Battery Cells: Perspective on Materials and Technologies. *Small Methods*. 4. 2000039. 10.1002/smt.202000039.
- EC DG Mobility and Transport. n.d. Accessed on 27.02.2022 from https://transport.ec.europa.eu/index_en
- European Commission (2017). Quantification of the effects of legal and administrative border obstacles in land border regions. Final report. Available online: https://ec.europa.eu/regional_policy/sources/docoffic/2014/boosting_growth/quantif_effect_borders_obstacles.pdf
- European Distribution System Operators (E.DSO) (n.d.). Distribution system operators (DSOs). Available at: <https://www.edsofsmartgrids.eu/home/why-smart-grid>
- Europa.eu. 2021. Communication from the Commission to the European Parliament, The Council, the European Economic and Social Committee and the Committee of the Regions 'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutralityCOM/2021/550 Accessed on 2 March 2022 from: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0550>
- EU -lex Energy. n.d. Access to European Union Law. Energy. Available at: https://eur-lex.europa.eu/summary/chapter/energy.html?root_default=SUM_1_CODED=18
- Fan et al., 2021: Fan, Xiaoping, Chunlei Tan, Yu Li, Zhiqiang Chen, Yahao Li, Youguo Huang, Qichang Pan, Fenghua Zheng, Hongqiang Wang, et Qingyu Li. 2021.In A Green, Efficient, Closed-Loop Direct Regeneration Technology for Reconstructing the LiNi0.5Co0.2Mn0.3O2 Cathode Material from Spent Lithium-Ion Batteries. *Journal of Hazardous Materials* 410 (mai): 124610. <https://doi.org/10.1016/j.jhazmat.2020.124610>.
- Fraunhofer Institute for Solar Energy Systems-ISE (2020). Agrivoltaics: Opportunities for Agriculture and the Energy Transition. Available at: <https://www.ise.fraunhofer.de/content/dam/ise/en/documents/publications/studies/APV-Guideline.pdf>
- Boons, F., Montalvo, C., Quist, J., Wagner, M. (2013). Sustainable innovation, business models and economic performance: an overview, *Journal of Cleaner Production*,(45),1-8, <https://doi.org/10.1016/j.jclepro.2012.08.013>.
- Gernaat, D.E.H.J., de Boer, H.S., Daioglou, V. et al. (2021) Author Correction: Climate change impacts on renewable energy supply. *Nat. Clim. Chang.* (11), 362. <https://doi.org/10.1038/s41558-021-01005-w>
- Hafenverwaltung Kehl. 2015. Deutsche Häfen am Oberrhein. Retrieved from: https://www.raonline.ch/pages/edu/st4/wawa_rhein0102a.html
- Harlé P , Kushnir A. R.L., Aichholzer C., Heap M. J., Hehn R., Maurer V., Baud P., Richard A. , Genter A. & Düringer P. (2019), Heat Flow Density Estimates in the Upper Rhine Graben Using Laboratory Measurements of Thermal Conductivity on Sedimentary Rocks, *Geothermal Energy*, 7 (1): art. 38, doi: <https://doi.org/10.1186/s40517-019-0154-3>

- Harper, G., Sommerville, R., Kendrick, E., Driscoll, L., Slater, P., Stolkin, R., Walton, A., Christensen, P., Heidrich, O., Lambert, S., Abbott, A., Ryder, K.Gaines, L., Anderson, P. (2019). Recycling lithium-ion batteries from electric vehicles. *Nature*. 575 (7781), 75–86.
- Hoffrage, U., Garcia-Retamero R. (2018). Improving understanding of health-relevant numerical information. In M. Raue, E. Lerner, & B. Streicher (Eds.), *Psychological Perspectives on Risk and Risk Analysis. Theory, Models, and Applications*. (279-298). Springer.
- Interreg Upper Rhine (2019). Analyse des Programmgebiets INTERREG V OBERRHEIN Endbericht. 11.06.2019. Available at: <https://www.interreg-oberrhein.eu/wp-content/uploads/3-analyse-des-programmgebiets.pdf>
- 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. doi: <https://doi.org/10.1016/j.renene.2016.05.013>.
- Jung, W., Engelke, D., Brester, B., Putlitz, A. 2012. Ulysses: Using applied research results from ESPON as a yardstick for cross-border spatial development planning. Scientific Report for the Final Report Multi-Thematic Territorial Analysis of the Upper Rhine Trinational Metropolitan Region. ESPON & Karlsruhe Institute of Technology. Available at: https://www.espon.eu/sites/default/files/attachments/ULYSSES_Final_Report_-_Scientific_Report_-_CS1_Upper-Rhine_MTA.pdf
- Komiyama, H., Takeuchi, K. (2006). Sustainability science: building a new discipline. *Sustainability Science* 1 (1): 1–6.
- Langstädtler, S. (2021). Brauchen wir ein Wasserstoffinfrastruktur Gesetz? Zum planungs- und genehmigungsrechtlichen Rahmen für die Erzeugung, Verteilung und Speicherung von grünem Wasserstoff. *ZUR Zeitschrift für Umweltrecht*. 32(4), 203-211.
- Li, X., Zhang, J., Song, D., Song L., Zhang, L. (2017). Direct Regeneration of Recycled Cathode Material Mixture from Scrapped LiFePO₄ Batteries . *Journal of Power Sources*. (345). 78-84. doi: <https://doi.org/10.1016/j.jpowsour.2017.01.118>.
- Lopez, A., Roberts, B., Heimiller, D., Blair, N., Porro, G. 2012. U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis. Technical Report NREL/TP-6A20-51946 July 2012. Available online: <https://www.nrel.gov/docs/fy12osti/51946.pdf>
- Loi 2019-1147 (2019). LOI n° 2019-1147 du 8 novembre 2019 relative à l'énergie et au climat. Available at: LOI n° 2019-1147 du 8 novembre 2019 relative à l'énergie et au climat - Dossiers législatifs - Légifrance
- Miocic, J. (2021). Hydrogen storage in the Upper Rhine Graben. Potential analysis. Report Work Package 2.2. Available at: https://www.res-tmo.com/fileadmin/PDFs/Outputs/RES_TMO_Bericht_H2_Speicherung_ORG_EN.pdf
- Mossali, E., Picone, N., Gentilini, L., Rodríguez, O., Manuel Pérez, J., Colledani, M. (2020). Lithium-Ion Batteries towards Circular Economy: A Literature Review of Opportunities and Issues of Recycling Treatments. *Journal of Environmental Management*.(264),110500. National Renewable Energy Laboratory n.d. Accessed on 21.02.2022 from <https://www.nrel.gov/>
- Neef, C., Schmalz, T., Thielmann, A. (2021). Recycling von Lithium-Ionen-Batterien: und Herausforderungen für den Maschinen- und Anlagenbau Kurzstudie im Auftrag der IMPULS-Stiftung (Stiftung für den Maschinenbau, den Anlagenbau und die Informationstechnik) Recycling of Lithium-Ion Batteries: Opportunities and Challenges for Mechanical and Plant Engineering. Available at: https://publica.fraunhofer.de/eprints/urn_nbn_de_0011-n-6434738.pdf
- Patenaude, J. (2014). Assessing the Social Acceptability of New Technologies: Gaps and Tensions Between Science and Regulation. *BioéthiqueOnline*. Available at: https://www.researchgate.net/publication/269573770_Assessing_the_Social_Acceptability_of_New_Technologies_Gaps_and_Tensions_Between_Science_and_Regulation
- Peters, E, Västfjäll, D., Slovic, P., Mertz, C.K., Mazzocco, K., & Dickert, S. (2006). Numeracy and decision making. *Psychological Science*, 17, 407-413.
- Ribon et al., 2018: Ribon B., Badariotti D. et Kahn R. 2018. Fondements des analyses de flux de matières et d'énergie et typologies d'applications pour la gouvernance des territoires et des organisations. *Vertigo* - la revue électronique en sciences de l'environnement, Volume 18 numéro 2. DOI: 10.4000/vertigo.20822
- Regierungspräsidium Freiburg, n.d., Upper Rhine. Accessed on 20. December 2021 at: <https://rp.baden-wuerttemberg.de/rpf/sgz-en/upper-rhine/>
- Samsatli, S. , Samsatli, J.N (2019). The role of renewable hydrogen and inter-seasonal storage in decarbonising heat – Comprehensive optimisation of future renewable energy value chains. *Applied Energy*, (233–234). 854-893. <https://doi.org/10.1016/j.apenergy.2018.09.159>.
- Schumacher et al. (Eds.) (2017): Schumacher K., Fichtner W. & Schultmann F., Innovations for Sustainable Biomass Utilization in the Upper Rhine Region, KIT Scientific Publishing, doi: <https://doi.org/10.5445/KSP/1000048433>

Spangenberg, J. (2011). Sustainability science: A review, an analysis and some empirical lessons. *Environmental Conservation*, 38(3), 275-287. doi:10.1017/S0376892911000270

Specht, M., Zuberbühler, U.; Wittstadt, U. (2004). Regenerativer Wasserstoff - Erzeugung, Nutzung und Syntheserohstoff. Stadermann, G.; Forschungsverbund Sonnenenergie -FVS-: Wasserstoff und Brennstoffzellen-Energieforschung im Verbund: Jahrestagung des Forschungsverbunds Sonnenenergie, 25.-26.11.2004 in Berlin
Berlin: FVS, 2005 (Forschungsverbund Sonnenenergie. Themen 2004) S.33-40 Available at:
Regenerativer Wasserstoff – Erzeugung, Nutzung und Syntheserohstoff

Tarascon et al., 2021: Tarascon, J.-M. 2021. Batteries: Constituants, Évolution des recherches, Batterie 2030+. Le tout en 5 min. Webinar, April 13. <https://www.concer-tation-acc-batteries.fr/compte-rendu-et-replay/7>.

The Upper Rhine Conference. (2020). Oberrhein Statistical Brochure . Retrieved from: https://www.oberrheinkonferenz.org/de/statistik/downloads.html?file=files/assets/ORK/docs_de/allgemein/broschueren/statistikbroschuere-oberrhein-2020.pdf&cid=2792



Résumé du Rapport

Étude de faisabilité Région d'innovation de Fessenheim
2021 – 2022

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L'étude de faisabilité vise à identifier des voies de transformation viables pour le secteur de l'énergie connecté à une industrie durable orientée vers l'avenir, intégrant des études pertinentes, des partenaires scientifiques et parties prenantes de la société ainsi que de l'industrie/de l'économie.

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01. Introduction

La nécessité du développement durable a dominé le discours sur la politique environnementale au XXI^e siècle, ce qui en fait un paradigme politique primordial (Komiyama et Takeuchi, 2006; Spangenberg, 2011). Au fil du temps, le rôle des innovations radicales et systémiques a été au premier plan de la réalisation des objectifs de développement durable (Boons et al., 2013).

L'étude de faisabilité «Région d'innovation de Fessenheim» s'inscrit dans la même logique d'innovations durables. L'étude se concentre sur le développement d'une région d'innovation pilote basée sur de nouvelles technologies innovantes afin d'atteindre la neutralité des émissions et la durabilité du système énergétique, et de promouvoir la valeur ajoutée locale et la création d'emplois. Sur la base d'un accord bilatéral, l'étude de faisabilité développera un modèle de référence pour le développement régional européen transfrontalier. L'étude propose des idées de projets pilotes, en particulier dans les domaines des « batteries vertes », de l' « hydrogène vert » et des « réseaux intelligents », et met en lumière les liens et les co-bénéfices de leur mise en œuvre potentielle (figure 1).

En utilisant une approche interdisciplinaire et orientée vers la pratique, l'étude de faisabilité vise à impliquer des partenaires et des parties prenantes issus des milieux scientifiques, économiques, politiques, de l'administration publique et de la société civile afin de faire progresser la défossilisation du système énergétique et, par conséquent, de l'économie de la région. Le projet utilise les compétences présentes dans le Cluster du Rhin supérieur pour la recherche sur la durabilité (URCforSR), telles que les instituts de recherche individuels, Eucor – le Campus européen, et TriRhenaTech, pour former une coalition globale. L'objectif principal et la force de l'étude consistent à réunir les vastes connaissances et compétences scientifiques de la vallée du Rhin supérieur avec les connaissances pratiques de l'industrie et des acteurs de la société. À la suite des études trinacionales précédentes (RES-TMO, Smart Meter, SumoRhine) et des études du Projet de Territoire, quatre éléments importants ont été identifiés pour le développement de la région d'innovation:

1. La démonstration de nouveaux concepts technologiques liés à l'innovation en matière d'énergie durable par le biais de laboratoires vivants régionaux susceptibles de fournir à l'avenir des résultats tangibles aux citoyens.
2. La connexion entre l'expertise scientifique existante de la région et les investissements industriels par le biais des pôles de transformation et d'innovation.
3. Le développement de concepts d'intégration des domaines de la formation, de la formation continue et de l'enseignement pour continuer à dynamiser la région modèle.

4. L'initiation d'un discours avec les différentes communautés de la région sur la vision du projet et les pilotes d'innovation concrets ainsi que la prise en compte de leur contribution.

Ensemble, les éléments susmentionnés constituent les piliers du développement d'une région d'innovation transfrontalière et contribuent à l'idée principale de l'étude de faisabilité.

En intégrant des études pertinentes, des partenaires scientifiques et des parties prenantes de la société et de l'économie, l'idée principale de l'étude de faisabilité est d'identifier des champs de transformation viables pour la région d'innovation en prenant en compte dans l'équation la consommation régionale totale d'énergie primaire afin d'induire une transformation vers un marché industriel et énergétique orienté vers l'avenir. Plus précisément, la vision de l'étude est d'établir:

- Une région européenne d'innovation transfrontalière en connectant les acteurs régionaux du monde universitaire, de l'économie et de la société.
- Un modèle européen (Living Lab) comme exemple pour une transformation sociétale et industrielle vers la durabilité.

Dans cette optique, après avoir analysé les atouts régionaux du Rhin supérieur et de la région d'innovation de Fessenheim, des champs de développement répondant aux exigences des demandes politiques mises en avant dans le Projet de Territoire ont été identifiés. Les objectifs politiques décrits dans le Projet de Territoire s'inscrivent dans les objectifs européens, nationaux et régionaux visant à atteindre la durabilité et la neutralité climatique.

Parallèlement aux objectifs de transformation vers la durabilité et la neutralité climatique, le Projet de Territoire a postulé que la création de pôles d'innovation technologique dans la région conduit à:

- Un emploi orienté vers l'avenir
- Des industries de l'innovation
- Une éducation et formation transfrontalières
- La participation des citoyens

En reliant les objectifs postulés du Projet de Territoire et les atouts régionaux du Rhin supérieur et de la région d'innovation de Fessenheim, les idées pour le développement de pilotes comme exemples de bonnes pratiques sont basées sur quatre groupes de compétences. Trois groupes de compétences sont classés dans la catégorie des pôles d'innovation technologique:

1. Pôle d'innovation pour les batteries vertes et l'économie circulaire des batteries
2. Pôle d'innovation pour l'hydrogène vert
3. Pôle d'innovation pour les réseaux intelligents

En outre, le quatrième groupe de compétences, «cadre territorial», étudie les conditions environnementales, sociales, réglementaires et économiques générales pour la mise en œuvre des trois groupes de compétences des pôles d'innovation technologique (figure 1).

Concept de neutralité carbone pour l'énergie et le transport

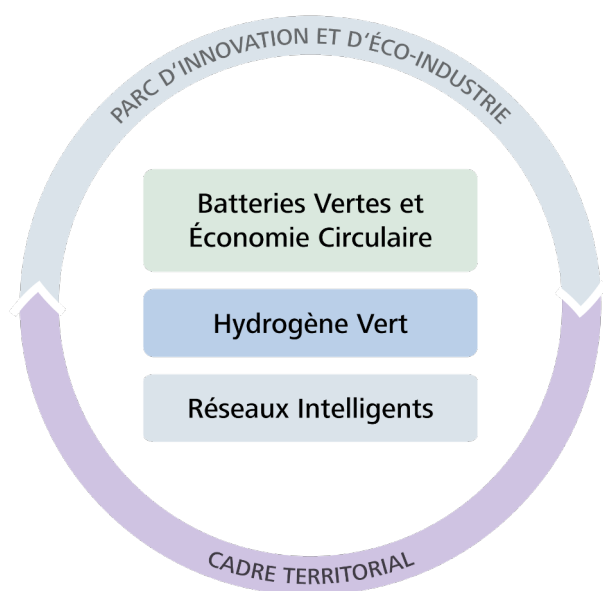


Figure 1. Champs d'innovation pour le développement d'exemples de bonnes pratiques intégrés dans les conditions territoriales générales et situés dans des parcs d'innovation et d'éco-industrie

Une autre idée-clé est que les pôles d'innovation technologique sélectionnés soient interdépendants, corrélés. Ils doivent être exécutés simultanément pour une transformation régionale réussie et durable. En effet, le lien entre les batteries et l'hydrogène vert est d'une grande importance pour la transformation régionale globale car ils sont complémentaires en termes de mise en œuvre d'un système de stockage pour les énergies renouvelables volatiles, de stabilisation du réseau et de contribution aux processus et applications du transport et de l'industrie. La temporalité et les différents moyens de transport apportent une sécurité et une flexibilité complémentaires dans le système énergétique (Specht et al., 2004). Par exemple, en termes d'applications industrielles, les batteries possèdent une grande flexibilité en termes de sources d'approvisionnement énergétique mais ne sont pas adaptées aux processus à forte intensité énergétique, tandis que l'hydrogène vert est particulièrement efficace et économe en énergie dans les processus industriels à forte intensité énergétique. D'autre part, en termes de transport, les batteries pourraient être utilisées pour le transport de passagers, tandis que l'hydrogène vert pourrait être plus performant que les batteries pour le transport lourd par bateau et par train. En outre, l'adaptation du réseau aux énergies renouvelables est nécessaire pour augmenter l'énergie fournie par ces dernières et peut être soutenue par les applications innovantes décrites dans les pôles d'innovation sur les batteries et l'hydrogène vert, car elles peuvent toutes deux contribuer à un approvisionnement en électricité suffisant et en temps voulu.

En gardant à l'esprit ce qui précède, les chapitres suivants développent les atouts locaux de la région de Fessenheim et donnent un aperçu des thèmes, des recherches et des recommandations de chacun des groupes de compétences afin de plaider en faveur de la mise en œuvre à grande échelle des projets pilotes complémentaires proposés.

02. Atouts régionaux et locaux pour la région d'innovation de Fessenheim

Comme mentionné dans l'introduction, les thèmes des groupes de compétences sont basés sur les objectifs politiques et les atouts régionaux de la région d'innovation de Fessenheim. Ce chapitre donne un aperçu de ces atouts régionaux.

La région innovante de Fessenheim est située dans la région du Rhin supérieur (territoire sous mandat de la Conférence du Rhin supérieur), une région géographiquement diversifiée située à la frontière triangulaire entre la France, la Suisse et l'Allemagne. Le Rhin est la principale voie de communication de la région et constitue sa frontière naturelle. La région est caractérisée par la vallée du Rhin qui est entourée par les régions montagneuses des Vosges à l'ouest et de la Forêt-Noire à l'est. Les contreforts du Jura en Suisse se trouvent à la limite sud. La région métropolitaine trinationale est habitée par plus de six millions de personnes (Jung et al., 2012) et affiche une forte performance économique (PIF 272 milliards/an) (Regierungspräsidium Freiburg, n.d.). La région de Fessenheim est directement reliée à une infrastructure de transport bien connectée comprenant trois corridors de transport européens, les gazoducs européens bien construits et le réseau électrique européen à haute tension (DG Mobilité et Transports de la CE, n.d.).

La région du Rhin supérieur est apte à devenir le pôle d'innovation dans les domaines mentionnés ci-dessus pour de nombreuses raisons. Tout d'abord, la région présente un potentiel économique élevé qui se manifeste par un PIB de 272 milliards d'euros par an, soit plus que celui de la Finlande et de l'Irlande réunies (Regierungspräsidium Freiburg, n.d.). En outre, l'infrastructure industrielle existante dans la région favorise le développement des petites et moyennes entreprises (Interreg Rhin supérieur, 2019). Par conséquent, étant donné que les activités industrielles transfrontalières sont fortement développées, les projets transfrontaliers d'investissement conjoint peuvent apporter une grande valeur ajoutée. Une étude européenne a en effet estimé que le potentiel de relance dans les régions frontalières peut atteindre une croissance de 485 milliards d'euros s'il est accompagné d'une réduction importante des barrières juridiques et administratives (Commission européenne, 2017) qui sont responsables d'une perte de 3% du PIB européen (Commission européenne, 2017). À juste titre, la présente étude de faisabilité se concentre sur les pôles d'innovation sans obstacles. En 2018, la région du Rhin supérieur comptait environ 3,2 millions d'emplois. 97 000 travailleurs faisaient la navette avec les pays voisins, dont 61% en Alsace et 38% à Baden Baden. Le nombre de travailleurs transfrontaliers a augmenté de 12% par rapport à 2008 (Conférence du Rhin supérieur, 2020).

Selon l'étude sur les régions transfrontalières du rapport 2017 de la Commission européenne (CE), le nombre d'employés peut être stimulé par des investissements

communs. En effet, seulement 2% des citoyens de l'Union européenne (UE) traversent les frontières nationales au sein de l'UE, mais 66% des citoyens le long des régions frontalières traversent régulièrement les frontières nationales au sein de leur région (Commission européenne, 2017). Le potentiel de développement de nouveaux lieux de travail dans les régions transfrontalières européennes a été estimé à huit millions par le rapport de la Commission européenne publié en 2017. Par conséquent, les régions frontalières sont importantes pour une intégration européenne complémentaire et horizontale.

Les atouts de la région du Rhin supérieur, qui peuvent contribuer à la transformation et à la croissance durables de la région et à la valeur ajoutée pour la société et l'économie, sont les suivants:

Premièrement: Les industries chimiques et pharmaceutiques sont très importantes en termes de génération d'emplois et de création de valeur. Toutefois, pour rester compétitif au niveau mondial, il est impératif de transformer cette industrie régionale en une industrie plus efficace sur le plan énergétique et produisant moins d'émissions de CO₂. À cette fin, le transfert de technologies innovantes vers les entreprises doit être accru sur la base d'exemples de bonnes pratiques.

Deuxièmement: Le Rhin supérieur ne doit pas passer à côté d'investissements prometteurs dans le secteur des transports, dans le secteur énergétique ou dans la création d'une économie circulaire. Par exemple, en ce qui concerne le secteur des transports, la région a un grand volume de trafic et de commerce. Par conséquent, les réductions d'émissions dans le secteur des transports pourraient avoir un grand impact et aider à atteindre la neutralité climatique. En outre, la région du Rhin supérieur entretient des liens étroits avec l'industrie automobile ainsi qu'avec les technologies et les innovations pertinentes qui soutiennent la transformation du secteur des transports (y compris les composants de la construction automobile) vers la neutralité climatique. Il est également très important de suivre les dernières tendances en matière de neutralité climatique pour créer localement des lieux de travail tournés vers l'avenir.

Troisièmement: La région du Rhin supérieur occupe une position centrale en Europe et possède de nombreuses connexions et routes fiables qui permettent un transport multimodal et efficace des marchandises. L'infrastructure régionale de transport comprend: les corridors de transport existants Rhin-Alpes, Atlantique et Rhin-Danube qui relient les principaux ports maritimes européens Rotterdam - Gênes - Marseille (route maritime du Rhône) et les ports du Danube situés plus bas vers la mer Noire. En outre, d'importantes infrastructures ferroviaires et autoroutières existent le long des corridors de transport et

servent également de lien entre les routes maritimes. Les liaisons de transport les plus importantes dans le Rhin supérieur sont les liaisons nord-sud, qui offrent d'excellentes conditions pour le chargement et le déchargement des ports, ainsi que pour l'administration portuaire (Hafenverwaltung Kehl, 2015). En outre, d'importants gazoducs et lignes électriques européens se trouvent dans la région. Ces installations sont déjà prêtes à l'emploi et peuvent, si nécessaire, être adaptées pour transporter à l'avenir de l'électricité verte ou de l'hydrogène vert du nord au sud ou vers le réseau européen à haute tension dans d'autres directions.

Quatrièmement: Dans la région, il existe une forte concentration d'institutions de recherche et d'éducation, notamment des instituts mondialement reconnus dans les domaines de l'énergie, de la technologie et de la durabilité, des universités et des entreprises privées, ce qui offre une excellente occasion de créer un réseau solide pour l'innovation. Grâce à cette forte concentration, un grand nombre de jeunes gens présentant un bon niveau d'éducation et possédant les compétences requises à tous les niveaux de formation arrivent en permanence sur le marché du travail. La région du Rhin supérieur dispose donc de vastes ressources humaines pour une transformation technologique durable. En outre, les liaisons rapides entre l'Autriche (tous les jours), la France (tous les jours), la Suisse (tous les jours), l'Espagne (toutes les semaines), le Luxembourg (toutes les

semaines), la Belgique (toutes les semaines), les Pays-Bas (toutes les semaines) et l'Italie (toutes les semaines) sont attractives pour les jeunes Européens qui souhaitent travailler à temps partiel ou plus dans la région du Rhin supérieur.

Cinquièmement: Le traité d'Aix-la-Chapelle comprend des clauses expérimentales, qui peuvent être utilisées pour démontrer comment une intégration transfrontalière réussie (CBRIS) contribue à la valeur ajoutée d'une industrie d'innovation commune.

Outre les atouts régionaux évoqués précédemment, les atouts locaux de Fessenheim et de ses environs, tels que la disponibilité de ports, d'infrastructures de circulation, d'industries et de leurs usines, indiquent le potentiel élevé de la région à devenir un modèle européen de transformation régionale vers la durabilité.

Cependant, le succès de la mise en œuvre des pilotes recommandés dans les différents domaines d'innovation repose sur deux pierres angulaires: la viabilité d'un dossier commercial pour les premiers acteurs privés et la visibilité, le soutien et l'acceptation du public. Si toutes ces conditions sont remplies et le soutien politique est assuré, la mise en œuvre des pilotes recommandés pour une région économique durable et neutre en CO₂ sera rendue possible.

03. Potentiels en matière d'énergies renouvelables dans la région du Rhin supérieur

Au fil du temps, les ressources énergétiques renouvelables sont devenues des contributeurs importants à l'approvisionnement total en énergie primaire à l'échelle mondiale (Gernaat et al., 2021). La disponibilité des énergies renouvelables devient de plus en plus une condition préalable à la réussite de la transformation par les investissements. Le succès de la mise en œuvre du projet pilote est donc directement lié à la disponibilité de l'énergie verte. C'est pourquoi le rapport comprend un chapitre qui évalue le potentiel technique des énergies renouvelables dans la région du Rhin supérieur.

Sur son site Internet, le Parlement européen définit les sources d'énergies renouvelables comme suit: énergie éolienne, énergie solaire, énergie hydroélectrique, énergie des océans, énergie géothermique, biomasse et biocarburants. En juillet 2021, la Commission européenne a proposé d'augmenter la proportion d'énergies renouvelables dans le mix énergétique de l'UE dans le cadre des objectifs contraignants de la directive sur les énergies renouvelables et de la promotion des carburants renouvelables tels que l'hydrogène (EUROPA - Commission européenne, 2021).

Dans une étude réalisée dans le cadre du projet Interreg Rhin supérieur, « RES-TMO », le potentiel technique de production d'énergie renouvelable dans la région du Rhin supérieur a été examiné et les principaux résultats sont inclus ici en raison de leur importance remarquable pour l'ensemble du processus de transformation.

En ce qui concerne l'estimation du potentiel des énergies renouvelables, il est important de commencer par définir ce que l'on entend par énergies renouvelables (telles que définies ci-dessus) et par potentiels. La hiérarchie des potentiels peut être observée dans la figure ci-dessous en reprenant les définitions de Jäger et al. (2016). Les potentiels comprennent: les potentiels théorique, géographique, technique, économique et réalisable. Les enquêtes dans le cadre du projet RES-TMO s'arrêtent au niveau du potentiel technique car les derniers niveaux (économique et réalisable) doivent être calculés au cas par cas. Le potentiel technique prend en compte l'utilisation des terres, le système et les contraintes topographiques ainsi que les contraintes technologiques des technologies d'énergie renouvelable (Hafenverwaltung Kehl, 2015).



Figure 2: La hiérarchie des potentiels telle que définie par Jäger et al. (2016) et adaptée dans le cadre du projet RES-TMO.

Principales conclusions

L'éolien: Les résultats indiquent que le potentiel technique de production d'énergie éolienne dans la région du Rhin supérieur est de 128 TWh par an. Au niveau national, le potentiel technique éolien est relativement plus élevé en France et en Allemagne qu'en Suisse. La demande énergétique annuelle totale dans la région du Rhin supérieur a été estimée à environ 212.41 TWh par an, et la moitié de cette demande pourrait théoriquement être satisfaite par l'énergie éolienne. Cependant, les conditions économiques et réglementaires, ainsi que l'acceptation sociale de la technologie, limitent et réduisent le potentiel technique de l'énergie éolienne dans la région et il n'est pas réaliste d'espérer plus de 10% du potentiel technique.

L'énergie solaire photovoltaïque: La deuxième source d'énergie renouvelable importante dans la région est le solaire photovoltaïque (PV). Dans l'étude RES-TMO, le potentiel solaire PV dans le Rhin supérieur a été divisé en deux catégories: le PV sur toiture et le PV en plein air. Le PV en champ libre a été à nouveau divisé en deux sous-catégories qui dépendent de l'utilisation du sol: le PV au sol (GM) et le PV agricole (Agri).

1. PV sur les toits: Le projet RES-TMO a estimé que le potentiel technique du PV sur les toits est de 52 TWh par an, ce qui peut théoriquement couvrir environ 24% de la demande énergétique totale. Cependant, le potentiel technique total est limité par des restric-

tions, telles que la capacité de charge des toits, les effets d'ombre et les monuments protégés, ainsi que la volonté des citoyens d'investir dans les installations. L'acceptation sociale de cette source d'énergie renouvelable est relativement élevée (Cousse, 2021). Ce serait un succès si 40 à 50% des toits pouvaient être couverts de panneaux solaires à long terme ; toutefois, cela n'est réalisable que si toutes les conditions sont réunies.

2. PV en champ libre: Le potentiel technique du PV en champ libre est divisé en deux sous-catégories: Agri-PV et GM-PV. La différence entre les deux vient essentiellement du fait que l'Agri-PV tient compte de la double utilisation des terres arables pour la production d'énergie et de nourriture. Le potentiel technique estimé pour le PV en plein air (159.5 TWh par an) est important, mais seul un petit pourcentage de la surface utile calculée peut être couvert par des installations PV, en raison d'aspects environnementaux et sociétaux qui n'ont pas encore été pris en compte. En ce qui concerne la hiérarchie des potentiels, les potentiels économique et réalisable seront plus limités que le potentiel technique. Finalement, si 50% du potentiel technique de l'énergie solaire est utilisé sous forme de PV en champ libre, une contribution significative de près de 80 TWh par an aux besoins énergétiques totaux de la région du Rhin supérieur est possible.

L'hydroélectricité: L'hydroélectricité est une autre source d'énergie renouvelable étudiée par le projet RES-TMO. Le projet a conclu que la contribution de l'hydroélectricité de 13.6 TWh par an est limitée car les ressources hydroélectriques de la région sont déjà largement utilisées et presque épuisées, comme l'ont confirmé les autorités des deux côtés du Rhin.

La biomasse: La biomasse est de plus en plus utilisée aujourd'hui pour remplacer les combustibles fossiles dans les secteurs du transport et de l'énergie. Elle présente l'avantage, par rapport aux combustibles fossiles, d'être disponible au niveau régional en Europe et de pouvoir être stockée. Ce dernier point est un avantage par rapport aux sources d'énergies renouvelables intermittentes comme le vent et le soleil. Le projet RES-TMO a basé son estimation sur le projet «Biomass Oui» (Schumacher et al. (Eds.), 2017), qui a étudié en profondeur le potentiel de la biomasse dans la même région. Ce dernier, estimé à 5.2 TWh par an, est plutôt limité.

La géothermie: L'énergie géothermique est un autre type d'énergie renouvelable. Les sources d'énergie géothermique peuvent être différenciées entre les technologies utilisant le sous-sol peu profond (10 à 100 mètres de profondeur) et les méthodes exploitant le sous-sol profond (plusieurs milliers de mètres de profondeur) pour

Tableau 2a: Estimation de la consommation d'énergie dans la région du Rhin supérieur

Région du Rhin Supérieur (RRS)	Population en 2019*	Demande Énergétique Finale 2016 en MWh/habitant**	Demande Énergétique dans RRS en MWh/an***	Demande Énergétique dans RRS en TWh/an***
Suisse	1.507.718	49	73.878.182	73,88
Allemagne	2.858.606	26	74.323.756	74,32
France	1.888.480	34	64.208.320	64,21
Total	6.254.804		212.410.258	212,41

Tableau 2b: Estimation du potentiel technique des énergies renouvelables dans la région du Rhin supérieur

Source EnR	Potentiel Annuel (en TWh/an)
Éolien	128,0
Solaire PV Toit	52,2
Solaire PV Agri	91,5
Solaire PV Sol	68,0
Biomasse	5,2
Hydroélectrique	13,6

l'extraction d'énergie. L'énergie géothermique peu profonde est généralement utilisée pour fournir de l'énergie de chauffage ou de refroidissement, tandis que l'énergie géothermique profonde peut être employée à la fois pour la production d'électricité et le chauffage des locaux (Miocic, 2021). L'étude menée dans la Région Métropolitaine Trinationale du Rhin Supérieur (RMT), suggère que, bien qu'il y ait déjà plusieurs pompes à chaleur géothermiques (GSHP) installées dans la RMT, il y a encore de la marge pour que de nombreuses maisons individuelles de la région soient chauffées et refroidies avec des GSHP, en particulier lorsqu'elles sont combinées avec une rénovation basse consommation d'avenir. Ainsi, l'augmentation de la part des GSHP utilisées dans la RMT peut permettre une réduction drastique des émissions de carbone liées au chauffage et au refroidissement des locaux (Miocic, 2021). L'efficacité des puits géothermiques profonds dépend de la profondeur à laquelle les fluides chauds sont rencontrés ainsi que des propriétés des roches d'où proviennent les fluides. Sur le plan géologique, la RMT présente une forte densité de flux thermique qui conduit à des températures élevées dans le sous-sol relativement peu profond, et représente donc une région idéale pour l'exploitation géothermique profonde (Harlé et al., 2019). Cependant, les préoccupations sociétales concernant les risques sismiques doivent être sérieusement prises en considération, transformant les potentiels techniques en potentiels de faisabilité.

Conclusions

En conclusion, le potentiel technique des sources d'énergies renouvelables dans la région du Rhin supérieur s'élève à 358,5 TWh par an. Théoriquement, la totalité de la demande énergétique annuelle du Rhin supérieur pourrait être couverte sans même prendre en compte le potentiel géothermique.

Le potentiel technique est limité dans une large mesure par des facteurs tels que la concurrence en matière d'utilisation des terres pour la production alimentaire, les impacts environnementaux, les aspects paysagers, l'acceptation sociétale, les conditions économiques générales, les réglementations et autres. Au cas par cas, une estimation plus réaliste du potentiel, comme le potentiel économique et le potentiel réalisable, peut être calculée comme mentionné précédemment. Néanmoins, le potentiel technique soutient le développement de meilleures conditions cadres et d'espaces libres pour exploiter efficacement les potentiels par le biais d'une approche intégrative avec une forte participation des citoyens et des entreprises.

Sur la base de cette connaissance des potentiels des énergies renouvelables dans la région du Rhin supérieur, les idées pilotes ont été développées dans les domaines définis pour les pôles d'innovation. Leurs résultats sont présentés dans les chapitres suivants.

04. Batteries vertes et économie circulaire

Les installations pilotes nécessaires à l'établissement d'une économie circulaire des matériaux pour les batteries lithium-ion sont présentées ci-dessous. Les interconnexions (figure 4) entre ces usines pilotes, ainsi que les connexions avec les usines pilotes proposées par les autres groupes de compétences, y sont mises en évidence. En outre, les avantages spécifiques qui soutiennent les usines pilotes respectives de la région de Fessenheim sont discutés.

Les batteries lithium-ion jouent un rôle crucial dans la mise en place d'un secteur énergétique durable et neutre en carbone. Puisque la batterie lithium-ion est actuellement le type le plus développé de technologie de batterie avancée disponible, elle est largement utilisée notamment dans les véhicules électriques (VE). Si l'on considère le pronostic futur des batteries obsolètes présenté dans la figure 3, on

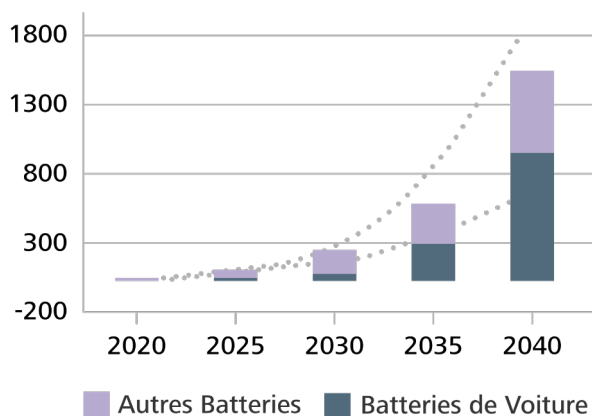


Figure 3: Pronostic du flux de recyclage de LIB en kt (élevé et faible) jusqu'en 2040 (Adapté de Neef et al., 2021)

peut noter que la mise en œuvre d'une économie¹ circulaire pour les batteries lithium-ion devrait être prioritaire en ce qui concerne les éventuelles usines pilotes dans la région de Fessenheim.

La figure 4 présente le cycle de vie d'une batterie et se concentre sur les domaines importants pour l'économie circulaire prévue mise en œuvre par les usines pilotes et décrite plus loin.

Pour mettre en place une économie circulaire telle que présentée dans la figure 4, le groupe de compétence Batteries Vertes suggère de se concentrer sur les domaines suivants à Fessenheim et dans la vallée du Rhin supérieur:

- Production de matériaux de batterie à haute performance et à faible empreinte environnementale, en utilisant des matériaux neufs et réutilisés.
- Qualification des batteries usagées de véhicules électriques en vue d'une éventuelle utilisation en seconde vie.
- Installation d'un stockage d'énergie électrique avec l'intégration de batteries de véhicules électriques de seconde vie.
- Développement d'une usine innovante de démantèlement et de recyclage des batteries en fin de vie.

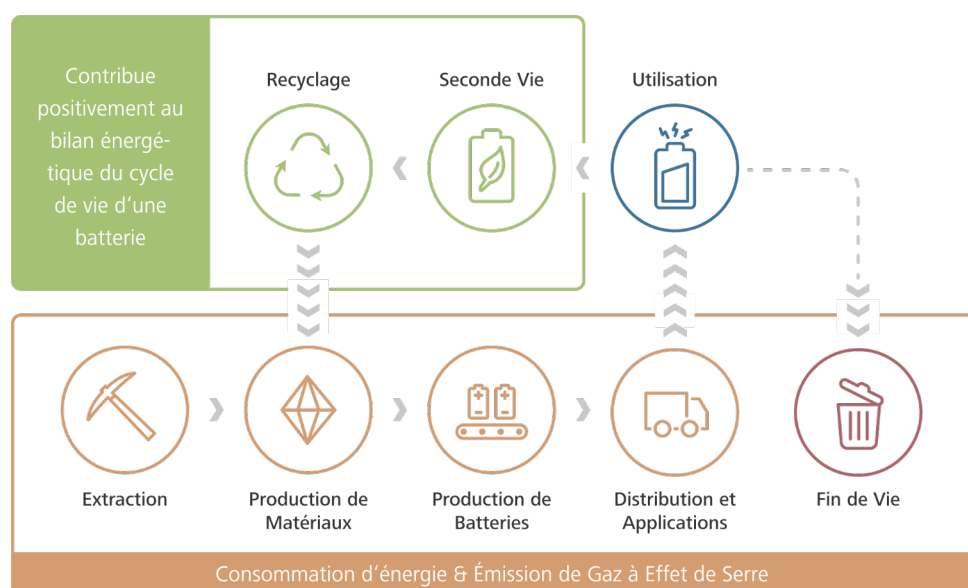


Figure 4: Cycle de vie d'une batterie (Dühnen et al., 2020).

¹L'économie circulaire (EC) est une approche régénératrice visant à réduire les déchets et à garantir l'éco-durabilité des produits après leur utilisation (Mossali et al., 2020).

Sur la base des points susmentionnés, trois pilotes principaux ont été identifiés :

- **Pilote 1:** Infrastructure pour l'utilisation en seconde vie des batteries de VE comprenant deux installations pilotes – un centre de qualification pour les systèmes de batteries de VE de seconde vie et un système hybride de stockage d'énergie électrique à l'échelle du service public, complété par des batteries de VE de seconde vie.
- **Pilote 2:** Infrastructure pour le démantèlement et le recyclage des batteries comprenant deux installations pilotes – une installation pour le démantèlement des batteries, y compris les diagnostics, et une installation pour le recyclage des matériaux des batteries.
- **Pilote 3:** Une usine de matériaux de batterie haute performance.

Il est important de noter que seule une approche globale de toutes les installations pilotes (voir les recommandations ci-dessous) permet d'obtenir les synergies souhaitées ainsi que des avantages économiques et environnementaux importants. Les installations proposées se complètent et offrent des opportunités commerciales significatives. C'est pourquoi le fait de ne pas mettre en œuvre toutes les installations proposées à proximité immédiate entraîne une réduction des avantages pour la région et nuit à sa compétitivité dans l'économie circulaire des batteries.

Les installations pilotes intégrées proposées présentent de nombreuses interconnexions, principalement liées à l'échange de matériaux et de savoir-faire technologique. En outre, toutes ces installations profiteraient fortement de l'infrastructure de transport existante dans la région, en particulier des ports le long du Rhin, qui offrent un grand avantage pour le transport économique et à grande échelle de minerais ou de batteries usagées. Les installations proposées par le sous-groupe «recyclage» et le sous-groupe «matériaux pour batteries» ont une forte demande énergétique qui doit être satisfaite par des sources d'énergies renouvelables dont le potentiel important a été évalué par le projet RES-TMO et discuté dans la section 3. En outre, les usines pilotes proposées bénéficieront des instituts de recherche et des universités de la région de Fessenheim, qui peuvent fournir l'expertise requise en matière de matériaux pour batteries. Les conditions précédentes font de la région un cadre idéal pour des collaborations avec des entreprises désireuses d'investir dans de telles installations. Enfin, il existe des liens avec les installations pilotes proposées par les groupes de compétences Batteries Vertes et Réseaux Intelligents et abordées dans les sections suivantes. Un exemple est le sous-produit de l'oxygène, rarement utilisé mais toujours présent, obtenu par la synthèse de l'hydrogène, qui est un réactif néces-

saire pour la fabrication des matériaux de batterie. Un autre exemple est le système électrique hybride envisagé par le sous-groupe « 2nd life », qui pourrait être intégré dans un réseau intelligent.

La région de Fessenheim offre des conditions favorables à l'installation de projets pilotes. Par ailleurs, les emplois sûrs générés par les installations prévues profitent mutuellement à la région de Fessenheim. Il n'y a pas d'alternative à l'économie circulaire en ce qui concerne les technologies de batteries (principalement les LIB), car le marché des batteries est en plein essor, ce qui entraînera à l'avenir une masse de batteries obsolètes. Les défis environnementaux, sociétaux et économiques exigent une plus grande infrastructure de recyclage des batteries et offrent une moindre dépendance aux matières premières hors d'Europe ainsi que des opportunités de croissance pour l'économie de la région. La figure 3 montre le développement attendu du flux de recyclage des LIB, or une capacité adéquate pour la seconde utilisation et le recyclage des batteries n'a pas encore été planifiée.

Recommandations

Afin d'établir une économie circulaire des batteries, il est crucial de localiser la chaîne de traitement complète dans la région. Par conséquent, il est recommandé d'établir un centre de qualification pour les systèmes de batteries de véhicules électriques de seconde vie et de le relier à un système de stockage d'énergie électrique hybride à l'échelle du service public complété par des batteries de seconde vie (pilote 1), tout en tenant compte de la logistique de collecte des batteries usagées et de distribution des packs de batteries de seconde vie aux utilisateurs industriels. L'idée pilote susmentionnée a déjà atteint un haut niveau de maturité technologique et le modèle économique est clair. Ce pilote devrait pouvoir être mis en place dans un avenir proche et il pourrait être possible d'utiliser des bâtiments industriels existants pour mettre en œuvre le centre de qualification.

En ce qui concerne le pilote 2, il est recommandé d'établir une infrastructure pilote servant de banc d'essai pour de futures installations industrielles axées sur le démantèlement et le recyclage des batteries. Le démantèlement est un processus étroitement lié à la qualification des batteries (pilote 1) et doit être effectué de manière automatisée (à l'aide de robots). Après le démantèlement, la première étape du processus de recyclage des batteries est basée sur un processus de broyage mécanique (déchiquetage mécanique des cellules de batteries). Ce processus de broyage permet d'obtenir ce que l'on appelle la masse noire, qui est utilisée pour l'extraction des éléments de valeur (principalement le cobalt et le nickel). À l'issue du processus de recyclage, ces éléments sont obtenus sous

une forme qui permet de les utiliser comme matières premières pour la production de nouveaux matériaux de batterie (pilote 3). L'ensemble du processus de recyclage doit inclure des unités de diagnostic qui sont importantes pour la réutilisation des matériaux recyclés comme matières premières. Bien que des éléments bruts précieux et critiques pour la réutilisation puissent être obtenus à partir du recyclage des batteries lithium-ion, de nombreux défis liés aux nouvelles innovations doivent encore être relevés. En effet, le groupe consultatif sur les batteries de l'Agence californienne de protection de l'environnement (CalEPA, 2021) a recommandé la mise en place de projets de démonstration tels que ceux suggérés dans le pilote 2 pour le recyclage des batteries lithium-ion afin d'améliorer nos connaissances sur les performances (c'est-à-dire la durée de vie, le taux de dégradation) et la sécurité des processus de recyclage. Ces bancs d'essai sont nécessaires de toute urgence pour accroître la confiance du public, garantir la meilleure utilisation des matériaux et tester leur faisabilité économique. Il est également recommandé d'établir les deux infrastructures pilotes en même temps, afin de tester l'ensemble du processus de recyclage à proximité immédiate.

Le recyclage des batteries est étroitement lié à l'idée d'une usine de matériaux pour batteries (pilote 3) ; il est donc recommandé de mettre en place une infrastructure pour le développement et la production de nouveaux matériaux

pour batteries à partir de matières premières recyclées seules ou associées à de nouvelles matières premières. L'innovation consistant à intégrer les matières premières recyclées des anciennes batteries dans la production de nouveaux matériaux de batterie est une tâche futuriste en cours et nécessite une coopération étroite entre la science et l'industrie.

Nous recommandons que ces usines pilotes complémentaires soient mises en œuvre en tant qu'entité afin d'optimiser les bénéfices des synergies qui en résultent, principalement l'échange de matériaux (réduction du transport) et de savoir-faire (nouvelles innovations) (figure 5).

La construction de ces installations nécessite des investissements conséquents. Il est essentiel de convaincre les industriels que le recours combiné à des financements transfrontaliers (contexte local) et européens (dans le cadre du Pacte Vert) est une opportunité d'obtenir des fonds plus importants pour mieux surmonter les besoins en investissement. Par ailleurs, il est vivement conseillé d'installer les usines pilotes dans la zone de l'euro district Breisach - Biesheim - Fessenheim. Son infrastructure portuaire est en effet compatible avec une plateforme logistique trimodale. Enfin, cette zone est propice à l'installation des infrastructures correspondantes puisqu'elle compte un grand nombre de sites potentiels sans compter que l'énergie renouvelable peut y être récoltée de part et d'autre de la frontière.

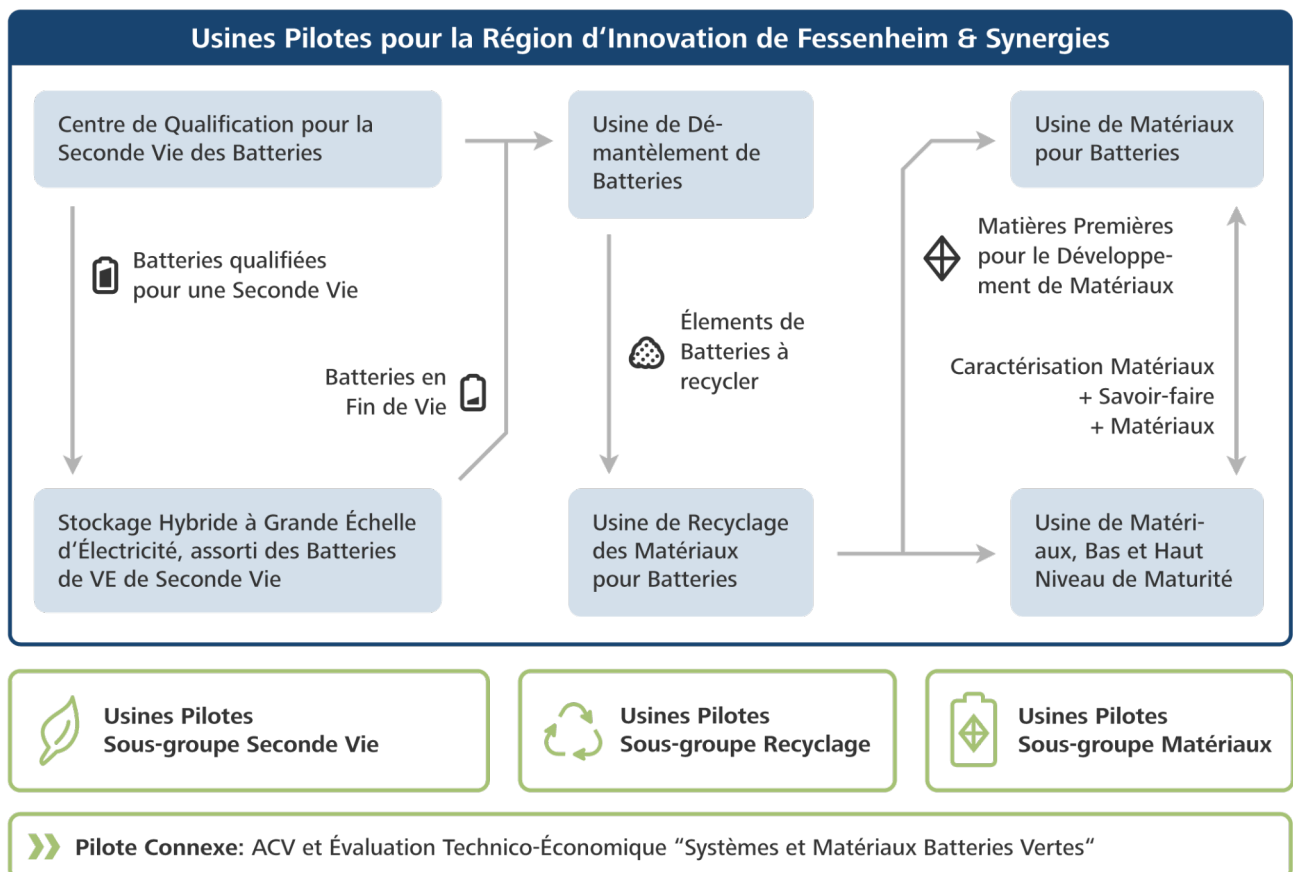


Figure 5: Représentation schématique du pilote principal suggéré par le groupe de compétence sur les batteries

05. Centre multimodal de l'hydrogène à Fessenheim

La mise en œuvre de l'hydrogène en tant que vecteur énergétique offre des possibilités uniques pour une intégration plus large des énergies renouvelables et une utilisation optimisée des ressources, ainsi que pour la création d'emplois d'avenir. Sa mise en œuvre garantit en définitive le développement de la région en une région économique durable et tournée vers l'avenir, neutre en termes de CO₂. L'hydrogène permet le stockage saisonnier de l'électricité renouvelable et aide à construire un système énergétique plus robuste en couplant les différents secteurs de manière flexible et efficace (Samsati & Samsati, 2019). En outre, plusieurs grandes entreprises qui utilisent l'hydrogène dans leurs processus sont situées dans la région autour de Chalampé et dans la région de Bâle. Un autre point-clé est le fait que la région regorge d'éléments, de projets et d'acteurs régionaux qui peuvent collectivement former le centre multimodal de l'hydrogène et couvrir toute la chaîne de valeur, de la production à l'utilisation en passant par la distribution.

Ces conditions de soutien ainsi que la diversité et la complémentarité de la région ont été révélées par le « South Rhine H2 Summit » qui a été organisé en novembre 2021 à Biesheim (Haut-Rhin) par la Collectivité européenne d'Alsace. Les résultats de l'étude montrent que la demande de l'industrie en hydrogène vert est considérablement plus élevée que dans les autres secteurs. En outre, l'hydrogène actuellement produit de manière conventionnelle peut être (relativement) facilement remplacé par de l'hydrogène vert.

Il est donc suggéré que la construction du centre multimodal de l'hydrogène (figure 6) commence par la mise en place de capacités d'électrolyse à grande échelle. L'électricité verte disponible localement à grande échelle réduira les coûts de la production d'hydrogène vert. Cette étape initiale permettra également de montrer les avantages de l'utilisation des centrales hydroélectriques en service dans la région avec le solaire photovoltaïque, car les centrales hydroélectriques peuvent être utilisées la nuit et les jours sans soleil pour la production d'électricité.

En outre, les capacités d'importation d'hydrogène vert supplémentaire via le Rhin seront développées ultérieurement. La robustesse de l'infrastructure d'approvisionnement et la disponibilité de l'hydrogène liquide feront du centre multimodal une base commerciale pour l'énergie verte, en particulier lorsqu'elle s'accompagnera de l'extension du transport par conteneurs à un plan de transport multimodal et de la combinaison de l'infrastructure de transport disponible dans la région via l'eau, les routes et le rail. Dans ce cas, un terrain fertile est créé pour des applications plus distribuées de l'hydrogène vert dans la région, comme l'établissement d'une flotte de camions à hydrogène vert pour le transport lourd ou la décarbonisation des transports publics avec des bus et des trains à hydrogène. De même, la production et l'utilisation de plus en plus réparties de l'hydrogène vert et la promotion des « prosommateurs » d'hydrogène dans le secteur agricole exploiteront un autre atout régional en rapprochant les technologies de l'hydrogène du grand public et en les ancrant dans la région.

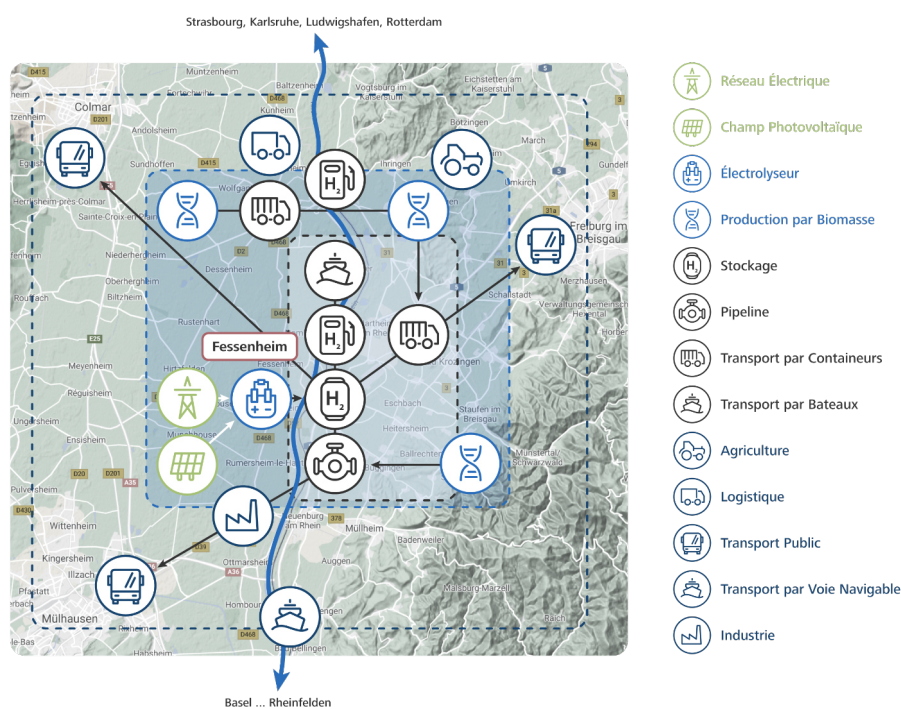


Figure 6: Principaux éléments du centre multimodal d'hydrogène dans la région de Fessenheim

l'hydrogène afin d'explorer les possibilités de production et d'application de l'hydrogène vert spécifiques à la région. Le centre multimodal de l'hydrogène reposera donc sur les quatre projets pilotes complémentaires suivants, qui couvrent les principales caractéristiques d'un système énergétique à base d'hydrogène opérationnel:

- **Pilote 1:** H2-A «Approvisionnement de l'industrie à grande échelle en hydrogène vert»
- **Pilote 2:** H2-B «Pipeline virtuel»
- **Pilote 3:** H2-C «Transport lourd»
- **Pilote 4:** H2-D «Production et utilisation distribuées en agriculture»

Recommandations

Tout d'abord, avec le pilote initial 1 H2-A, nous recommandons l'installation et l'exploitation d'un système d'électrolyseur à grande échelle de 200 MW situé près d'Ottmarsheim et de la zone industrielle de Chalampé. Cet emplacement est proposé en raison de sa proximité avec la zone industrielle de Chalampé et le nœud routier tri-modal franco-allemand d'Ottmarsheim (port, chemin de fer et autoroute). Pour une installation initiale d'environ 30 MW, il est proposé d'utiliser une petite fraction de l'électricité produite par les centrales hydroélectriques d'Ottmarsheim et de Fessenheim (chacune fournissant 160 MW nominaux) et de la combiner avec un système solaire PV flottant installé dans les bassins d'eau de ces centrales. D'autres installations solaires photovoltaïques flottantes sont proposées ultérieurement sur plusieurs lacs de gravier artificiels des environs. Le système d'électrolyseur devrait être installé à proximité et connecté via le pipeline d'hydrogène existant à la zone industrielle de Chalampé. La co-localisation avec la centrale électrique d'Ottmarsheim est optimale car elle offrira le double avantage d'utiliser l'infrastructure de distribution d'hydrogène existante et de fournir rapidement de l'hydrogène vert à l'industrie connectée. À terme, une extension de l'infrastructure locale de distribution d'hydrogène avec un pipeline parallèle à haute pression devrait être envisagée afin d'augmenter la capacité du pipeline d'hydrogène existant et d'améliorer la qualité de l'approvisionnement en fournissant une pression allant jusqu'à 100 MPa, ce qui est utile pour plusieurs applications, en particulier le transport (lien vers les projets pilotes H2-B et H2-C). La pression élevée permet d'utiliser des sections de tuyaux plus petites et intrinsèquement sûres et de transformer le pipeline en un système de stockage intermédiaire.

Deuxièmement, un approvisionnement complémentaire en hydrogène vert par le biais d'une option d'importation flexible est recommandé avec le projet pilote H2-B. La

construction de longs pipelines de transfert est généralement très coûteuse ; en outre, ces pipelines sont des structures rigides et peu flexibles. C'est pourquoi le concept pilote d'un « pipeline virtuel » est mis en place. Le projet pilote H2-B propose le transport discontinu d'hydrogène par conteneurs via le Rhin. La solution des conteneurs permet d'éviter les pertes dues au transfert entre les conteneurs fixes et les conteneurs de transport et de passer sans transition de l'hydrogène gazeux à haute pression à l'hydrogène liquide (LH2) plus dense. Le transport par conteneurs pouvant être facilement étendu des voies de navigation à un schéma de transport multimodal par rail et route, il ouvrira la voie à des applications distribuées loin des sites de ravitaillement établis dans le port industriel d'Ottmarsheim et/ou les voies de navigation de Fessenheim et rendra la distribution d'hydrogène plus flexible, robuste et économique. En outre, la disponibilité de l'hydrogène cryogénique catalysera la recherche, le développement et la démonstration de solutions innovantes, comme l'utilisation de supraconducteurs refroidis par l'hydrogène pour des lignes de transfert d'énergie électrique et chimique hybride ou des systèmes de stockage. Grâce au pipeline virtuel établi sur le Rhin, la région de Fessenheim sera directement reliée à Rotterdam, qui est voué à devenir le site d'atterrissage d'Europe centrale pour le LH2 provenant d'outre-mer. En outre, l'importation via le pipeline virtuel compensera à peu de frais le déficit potentiel d'approvisionnement en hydrogène vert laissé par la production locale. Compte tenu de ces éléments et avec le développement des capacités d'importation et d'exportation, la région de Fessenheim pourra se coordonner avec les différents sites de demande régionaux industriels situés le long et au-delà du Rhin et devenir la base commerciale transfrontalière de l'énergie verte.

Troisièmement, l'importante infrastructure routière transnationale reliant le nord de la Suisse, le Grand-Est en France et le sud-ouest de l'Allemagne a conduit de nombreuses entreprises de transport à exploiter des succursales dans cette région. Pour réduire l'empreinte CO₂ considérable du transport routier régional, il est recommandé, dans le cadre du projet pilote H2-C, d'établir un service à la demande qui offre aux entreprises des capacités de transport vertes basées sur l'hydrogène. S'inspirant du modèle commercial de la société suisse Hyundai Hydrogen Mobility, une entreprise du secteur des services achètera et exploitera une flotte de camions à hydrogène (20 à 30 au départ) et construira et exploitera l'infrastructure de ravitaillement nécessaire. Le fait de concentrer cette activité liée à l'hydrogène dans une entreprise du secteur des services permettra, d'une part, de négocier les meilleures conditions possibles (fiscalité, prix de l'hydrogène, etc.) et, d'autre part, de proposer des offres économiquement intéressantes aux clients. En conséquence, une station de ravitaillement en LH2 à la pointe de la technologie (capacité de distribution quotidienne initiale de 1

t, puis de 5 t) sera construite dans la région d'Ottmarsheim. La station sera caractérisée par une conception modulaire et comprendra une section de recherche et de développement indépendante, exploitée commercialement. La section commerciale alimentera de manière fiable la flotte de camions et fournira une capacité suffisante pour les petites flottes de bus à hydrogène exploitées à Mulhouse et/ou Fribourg-en-Brisgau. La section de recherche offrira des interfaces et une infrastructure flexibles pour développer de nouveaux protocoles d'alimentation en carburant pour poids lourds et pour tester les composants critiques, tels que les échangeurs de chaleur et les dispositifs de mesure.

Quatrièmement, la mise en œuvre de l'agrivoltaïque (agri-PV) pour la production locale d'hydrogène vert est recommandée dans le cadre du projet pilote H2-D «Production et utilisation distribuées en agriculture». L'utilisation de l'agri-PV sur les terres agricoles crée des avantages directs pour les agriculteurs. Outre le revenu supplémentaire généré pour les agriculteurs, l'agri-PV permet de protéger les plantes contre l'exposition directe au soleil, mais aussi pendant les tempêtes et la grêle (Fraunhofer ISE, 2020). Outre l'utilisation de l'électricité produite par le solaire PV et l'hydroélectricité, il est recommandé de tester et de développer davantage l'utilisation de la biomasse pour la

production locale d'hydrogène sur quelques sites prototypes. Dans le contexte de la production d'hydrogène renouvelable, la valorisation de la biomasse est une approche prometteuse, en particulier lorsque des biodéchets agricoles non valorisés peuvent être utilisés. En outre, l'utilisation de l'hydrogène dans l'agriculture sera démontrée, principalement dans les machines agricoles équipées de moteurs à combustion flexibles à carburant converti et dans les unités de production combinée de chaleur et d'électricité utilisant des piles à combustible à haute température. Comme on peut le constater, l'hydrogène offre de nouvelles possibilités pour le modèle commercial des coopératives agricoles en tant que négociants en carburant.

Comme nous l'avons vu plus haut, les projets pilotes sont complémentaires les uns des autres, car ils concernent différents domaines de production et d'application. Ils font appel à différentes technologies qui sont suffisamment mûres pour être mises en œuvre de manière programmée, et laissent un potentiel suffisant pour de nouvelles recherches et innovations. Bien que les projets puissent, en principe, être mis en œuvre indépendamment les uns des autres, le système global bénéficiera grandement d'une mise en œuvre intégrale, ensemble et dans l'ordre suggéré.

06. Réseaux intelligents

Dans le monde entier, et dans l'espoir qu'ils deviennent la norme pour les futurs réseaux électriques, les réseaux intelligents sont développés car ils sont technologiquement avancés et équipés pour optimiser la production et la consommation d'électricité. Les avantages des réseaux intelligents sont nombreux: d'une part, ils peuvent intégrer les nouvelles technologies de l'information et de la communication telles que les objets connectés et, d'autre part, ils sont capables de transmettre des informations en temps réel sur l'utilisation et la consommation d'électricité aux opérateurs du réseau (producteurs, distributeurs et consommateurs) (Butt et al., 2021). En fournissant des informations en temps réel sur les flux d'énergie, les réseaux intelligents permettent aux opérateurs de réseau de vérifier, contrôler, analyser et optimiser la consommation d'énergie. L'objectif des réseaux intelligents est d'utiliser ces informations collectées pour ajuster le flux d'électricité et, par conséquent, garantir des réseaux plus efficaces sur le plan énergétique. En outre, les réseaux intelligents assurent l'équilibre entre l'offre et la demande et empêchent la surchauffe des réseaux. Enfin, ils peuvent contribuer à combler le fossé dans la transition des ressources énergétiques des combustibles fossiles vers les énergies renouvelables (Butt et al., 2021).

D'une manière générale, les technologies de l'hydrogène

et les batteries vertes, qui font l'objet des deux groupes de compétences précédents, sont totalement dépendantes des réseaux intelligents pour l'analyse en temps réel de la consommation d'électricité. De plus, les réseaux intelligents permettent d'optimiser en temps réel l'utilisation de l'énergie, de réduire les pertes d'énergie et d'optimiser l'intégration des capacités de stockage des batteries dans le réseau pour une meilleure stabilisation. Il convient de noter ici que les réseaux intelligents sont parfaitement adaptés aux technologies d'énergie renouvelable, car ils peuvent être ajustés à tout moment en intégrant différentes sources d'énergie renouvelable sans compromettre l'efficacité, et ils contribuent implicitement à la réduction des émissions de carbone. Il est important de réaliser que la gestion intelligente de l'électricité est l'une des clés de la réussite de la transformation du marché de l'énergie. (Bayindir et al. 2016).

L'objectif du groupe de compétence sur les réseaux intelligents est de cartographier le système de transmission transnational régional existant et de recueillir des informations sur le potentiel des énergies renouvelables et son lien avec le développement de scénarios pour les réseaux énergétiques régionaux. En outre, l'objectif est d'étudier le potentiel de la gestion de la demande, et à cette fin, il est impératif d'identifier les éventuels points faibles en

termes de disponibilité de l'énergie. Les idées visant à actualiser le concept de connexion des réseaux électriques entre la France et l'Allemagne et à présenter les possibilités d'extension des réseaux de transport constituent un autre point fort de ce groupe. La mise en œuvre de tels concepts permet de comparer les alternatives techniques disponibles pour l'amélioration des réseaux et des connecteurs et soutient l'expansion vers plus d'énergies renouvelables. Le développement de concepts discrets permet également de trouver de meilleures idées pour optimiser la capacité de transmission des lignes aériennes existantes et d'analyser les exigences de sécurité du système dans les installations de production d'énergie renouvelable. L'un des principaux défis du concept transfrontalier consiste à intégrer la production fluctuante d'électricité issue des énergies renouvelables dans le réseau électrique transnational. L'objectif est donc de concevoir et d'exploiter un réseau de transport d'électricité qui soit à la fois flexible et adapté aux différentes installations de production d'électricité. Dans le cadre du concept d'innovation transfrontalier pour le territoire de Fessenheim, l'objectif est de concevoir et d'exploiter le réseau de transport d'électricité et de l'adapter aux différentes installations de production d'électricité ainsi qu'aux demandes de flexibilité accrue du système global.

L'analyse du groupe de compétence a mis en évidence des défis techniques tels que l'utilisation diversifiée de l'énergie, la sécurité et l'utilisation du réseau électrique, ainsi que l'intégration dans le réseau de l'e-mobilité et de nouvelles capacités de stockage. Ces défis incluent également les aspects économiques et sociétaux, comme des modèles économiques adaptés, l'acceptabilité sociale et les contraintes juridiques et de sécurité.

Pour mieux comprendre les défis régionaux, le groupe de compétence a organisé deux séminaires de travail en juillet et a associé les résultats à d'autres contributions des milieux scientifiques, industriels et communautaires. Les résultats de ces séminaires ont été réduits à des objectifs, décrits plus en détail dans le texte ci-dessous, qui ont guidé le développement des idées pilotes. En conséquence, il est apparu clairement que pour faire progresser les applications de réseaux intelligents, le réseau transfrontalier existant doit être cartographié afin d'identifier les faiblesses potentielles liées à l'augmentation de la part des énergies renouvelables dans le réseau, notamment en ce qui concerne les connecteurs et les charges électriques des différents systèmes de réseaux nationaux pour les niveaux de moyenne et basse tension. Premièrement, l'ingénierie des réseaux électriques est nécessaire pour améliorer physiquement le réseau électrique régional existant. Ensuite, la mise en place de bancs d'essai pour des unités de voisinage plus petites, comme des parcs industriels ou des zones d'habitation, est également nécessaire pour comprendre fondamentalement la fonctionnalité des réseaux intelligents en intégrant des capacités de stockage

comme des batteries stationnaires ou des voitures électriques, afin de connaître les défis de la gestion des réseaux intelligents. Enfin, la fonctionnalité et l'impact des systèmes de réseaux intelligents sur la stabilisation des réseaux et la manière de gérer efficacement l'énergie doivent être testés en tant que méta-démonstrateur dans une situation transfrontalière, comme le parc EcoRhena peut le permettre.

Dans la région du Rhin supérieur, les acteurs industriels établis allant des producteurs d'énergie aux industries de consommation (gestion de l'énergie, chimie, automobile, etc.) et les services d'ingénierie existants sont des atouts pour le développement de projets pilotes de réseaux intelligents. En outre, les compétences techniques et scientifiques nécessaires à la mise en œuvre des projets pilotes sont disponibles dans la région. Notamment, un autre atout qui soutient les projets pilotes est l'engagement des autorités locales et de nombreuses entreprises dans des stratégies de modification des sites industriels ou des quartiers afin de réduire leur impact carbone, voire d'obtenir la certification ISO 50 001 (gestion de l'énergie). Afin de cerner tous les défis et toutes les possibilités d'innovation en matière de réseaux intelligents dans la région du Rhin supérieur, trois projets pilotes sont proposés:

- **Pilote 1:** Mise en place de quartiers jumelés, quartiers durables entre Mulhouse et– Karlsruhe.
- **Pilote 2:** Intégration de bornes de recharge électrique pour l'e-mobilité dans les quartiers et méta-démonstrateurs pour une gestion plus intelligente des énergies renouvelables.
- **Pilote 3:** Cartographie de la situation du réseau régional et modélisation des scénarios futurs pour le renforcement des réseaux régionaux afin d'échanger de l'électricité volatile sur différents niveaux de tension.

Recommandations

Le groupe de compétence « Réseaux intelligents » recommande l'installation d'un système de réseau intelligent (figure 7) dans deux quartiers (pilote 1) en France et en Allemagne, en tant que bancs d'essai pour la gestion des réseaux intelligents, comme la consommation d'électricité contrôlée et efficace à la demande. L'idée est d'intégrer des systèmes de réseaux intelligents dans des quartiers de Mulhouse et de Karlsruhe. Le lieu a été choisi en raison de l'ouverture des communes à la mise en place d'un tel pilote: à Karlsruhe, la mise en œuvre du réseau intelligent de voisinage a déjà commencé, tandis que la commune de Mulhouse est prête à investir dans cette idée. Il est recommandé de transférer le savoir-faire acquis à partir des systèmes de réseaux intelligents testés dans les deux quartiers vers la mise en œuvre prévue du parc d'innovation

franco-allemand EcoRhena, en tant qu'exemple de méta-démonstrateur transfrontalier. Ce pilote permettra d'atteindre les objectifs suivants : démontrer comment les réseaux intelligents favorisent la réduction de la consommation d'énergie, l'intégration et le stockage intelligent des énergies renouvelables, le couplage des sources d'électricité, la gestion de la chaleur et du froid et la création de modèles exportables.

Le groupe recommande de tester l'intégration des batteries d'e-mobilité dans le système de réseaux intelligents parallèlement à la mise en œuvre des quartiers intelligents (pilote 2) afin d'acquérir des connaissances sur la manière dont cette intégration peut améliorer la gestion du réseau électrique et sur la façon dont les obstacles techniques, économiques et sociétaux peuvent être résolus. Les objectifs de ce pilote sont d'améliorer la compréhension de la manière d'optimiser le réseau de stations de recharge d'un quartier et le couplage entre le réseau de charge et le réseau de distribution dans le but de réduire les pics de puissance avec l'utilisation du stockage par batterie de l'e-mobilité, d'obtenir le meilleur profil et les meilleurs modèles d'utilisation, de soutenir la standardisation transfrontalière des réseaux de recharge. À cette fin, les stations de recharge de l'e-mobilité pour les voitures et les vélos doivent être incluses dans la conception des quartiers du réseau intelligent. Il est suggéré de commencer par les quartiers industriels en établissant des stations de recharge électrique qui serviront de bancs d'essai pour les applications du réseau intelligent. Le résultat pourrait être de montrer comment les stations de recharge d'e-mobilité

intégrées dans un réseau intelligent peuvent contribuer à économiser de l'énergie et à optimiser la distribution d'énergie en termes de disponibilité et d'accessibilité.

Une autre recommandation est de cartographier (pilote 3) le réseau électrique régional existant et d'analyser ses faiblesses pour optimiser les échanges transfrontaliers d'électricité, ainsi que d'étudier sa capacité à se stabiliser en cas de production d'électricité volatile. Les objectifs de ce pilote sont basés sur la politique énergétique de l'Union européenne, qui comprend la stabilisation du réseau en maintenant la fréquence à 50 Hz, l'optimisation et la décarbonisation du mix énergétique, et l'intégration des réseaux locaux au réseau transnational. Les capacités des réseaux existants et les simulations de profils de charge pour les différents scénarios d'installations renouvelables fournis par l'étude RES-TMO devraient faire partie de ce pilote.

Par ailleurs, le groupe de compétence sur les réseaux intelligents n'a pas pris en compte le réseau de gazoducs parce qu'il ne s'agissait pas de son objectif principal, mais il recommande que ce facteur soit étudié comme prochaine étape pour assurer une transformation énergétique intégrée.

Enfin, chacun de ces projets pilotes nécessite des ressources substantielles et la participation des opérateurs de réseau ainsi que des communautés et de l'industrie.

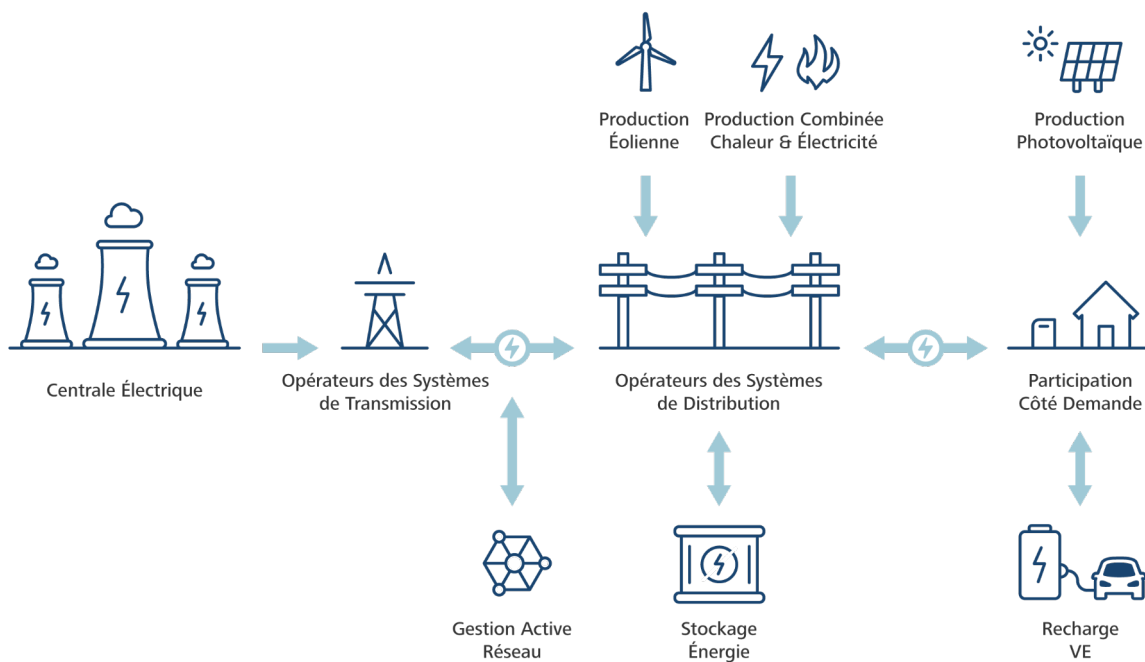


Figure 7: Un banc d'essai possible pour un système de réseau intelligent dans les projets pilotes de quartier (Source: Gestionnaires de réseaux de distribution européens (E.DSO))

07. Cadre territorial

La région du Rhin Supérieur est forte d'une expertise scientifique qui lui permet de faire face aux défis technologiques que peut représenter toute idée innovante. Le principal défi à surmonter reste cependant le défi territorial. Le territoire est en effet un objet complexe, et encore plus complexe lorsqu'il revêt une nature transnationale. Le territoire possède de multiples dimensions, dans lesquelles le projet global doit s'inscrire.

Le groupe de compétence « Cadre territorial » est un groupe de recherche franco-allemand pluridisciplinaire qui s'articule autour de quatre piliers thématiques: acceptabilité sociale, impact environnemental, métabolisme territorial et cadre juridique. Mis bout à bout, ces piliers permettent de dessiner les conditions générales de la région d'innovation de Fessenheim. Ce groupe accompagne les trois autres groupes de compétence de l'étude de faisabilité dans le développement d'idées concrètes pour le territoire (figure 8). Son objectif est de dresser le tableau complet des aspects territoriaux qui pourraient avoir un impact sur le projet dans son ensemble. Les principales conclusions sont résumées dans les paragraphes thématiques qui suivent, et sont accompagnées de recommandations potentielles quant aux mesures à prendre.

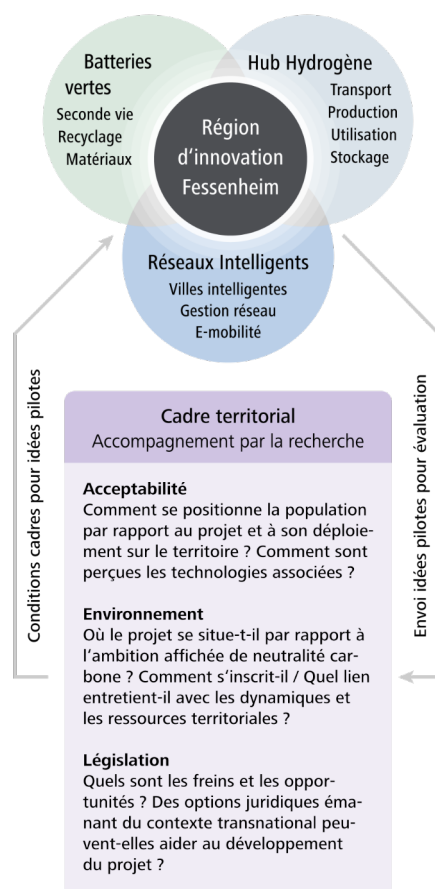


Figure 8: L'interconnexion du groupe « Cadre territorial » et des autres groupes de compétences

Recommandations

► Acceptabilité sociale

L'acceptabilité sociale des nouvelles innovations est cruciale (Patenaude, 2014). Les besoins, les perceptions et les changements possibles de la société ainsi que les questions éthiques doivent être pris en compte. Il ressort des études menées que les technologies vertes ont généralement le soutien du public. L'hydrogène semble être la technologie la plus acceptable, suivie des batteries vertes puis des réseaux intelligents. Un examen plus approfondi des différents paramètres révèle que la connaissance objective a peu d'influence sur le niveau d'acceptabilité et que la confiance [dans les différentes parties prenantes] a un effet modeste mais réel. Les leviers les plus prometteurs qui ont été identifiés et qui sont susceptibles d'avoir un impact positif sont l'image véhiculée (affect) et les bénéfices associés. Tous deux sont en effet positivement corrélés au niveau d'acceptabilité. À cet égard, l'hydrogène, en plus d'être la technologie la plus acceptable, véhicule l'image la plus positive et présente le meilleur rapport bénéfices-coûts par rapport aux deux autres.

C'est pourquoi nous recommandons une communication soignée. Plus l'image est positive (affect positif), plus le projet a de chances d'être considéré comme acceptable. De même en ce qui concerne les bénéfices: plus le projet est perçu comme une source de bénéfices, plus il a de chances d'être considéré comme acceptable. L'effet est encore plus prononcé pour les bénéfices environnementaux associés. La communication est essentielle pour construire l'image qui sera ensuite associée à la technologie/au projet. Par conséquent, les éléments de communication doivent être soigneusement conçus pour soutenir cet objectif (Bostrom et al., 2018 ; Hoffrage & Garcia-Retamero, 2018 ; Peters et al., 2006).

D'autre part, l'acceptabilité dépend également de la manière dont le déploiement du projet est envisagé sur le territoire. Une autre recommandation serait d'impliquer la population locale dès le début – de l'idée du projet à son développement concret. Le meilleur moyen d'y parvenir serait la transparence entre le promoteur et la population locale et la consultation dans le développement du projet. La co-construction du projet est donc un autre levier intéressant à explorer.

► Impact environnemental

Pour les projets innovants, la transformation verte d'un territoire implique le plus faible impact sur l'environnement (Söderholm, 2020). Tous les projets pilotes n'ont pas pu être individuellement évalués sur la durée de l'étude de faisabilité; pour cette raison, le choix a été fait de se concentrer principalement sur l'évaluation de l'impact des

différents scénarios possibles pour le recyclage des batteries lithium-ion (LIB) et les différents moyens de production d'hydrogène existants.

Le recyclage des LIB n'en est encore qu'à ses débuts, mais il sert deux objectifs ultimes: limiter le dépôt de batteries dans les décharges et diminuer la pression sur les ressources rares (Harper et al., 2019). Quatre scénarios de recyclage ont été étudiés, chacun consistant en une combinaison spécifique de processus élémentaires. Alors que les données concernant les processus de recyclage des LIB sont encore rares, l'analyse d'impact a mis en évidence un scénario comme étant le plus efficace d'un point de vue environnemental. En outre, il est encore possible d'optimiser les processus de recyclage et de réduire encore leur impact sur l'environnement (utilisation de produits chimiques moins polluants). Il est également intéressant de noter que d'autres technologies innovantes méritent d'être prises en considération, car elles pourraient permettre de raccourcir la boucle du modèle d'économie circulaire. Par exemple, la régénération directe permettrait de remettre à neuf les batteries au lieu d'en produire de nouvelles à partir de matériaux récupérés (Li et al., 2017; Fan et al., 2021). Des batteries de type «LEGO» qui faciliteraient considérablement le démantèlement pendant le processus de recyclage sont également en cours de développement (Tarascon et al., 2021). Les deux technologies mentionnées précédemment permettraient d'obtenir des impacts environnementaux encore plus faibles.

En ce qui concerne l'hydrogène, plusieurs moyens de production ont été évalués. L'étude a montré que l'électrolyse à haute température est effectivement le meilleur compromis du point de vue environnemental, surtout si l'infrastructure est alimentée par un réseau de vapeur sur place. La production d'hydrogène par électrolyse est en accord avec l'ambition affichée de réduire les émissions de gaz à effet de serre et de tendre vers la neutralité carbone.

► Métabolisme territorial

Un territoire est une entité vivante dont le métabolisme peut être étudié afin d'analyser les ressources mobilisées et de questionner l'ancrage territorial d'un projet (Ribon et al., 2018). La sélection d'indicateurs pertinents permet de mesurer la connexion potentielle aux dynamiques territoriales existantes et d'identifier les zones d'implantation préférentielles. S'appuyer sur le tissu industriel existant et créer des synergies par un couplage sectoriel constitue une stratégie gagnant-gagnant qui, à terme, permettra non seulement de fournir des sources d'énergie alternatives et décarbonées mais aussi de défossiliser les modes de production des industries existantes.

Le projet Batteries Vertes s'appuie sur le marché en pleine expansion de l'e-mobilité. L'approche de l'économie circulaire est essentielle à cet égard et offre des perspectives

intéressantes pour une seconde vie et le recyclage des batteries en fin de vie. La taille du pilote répond à la demande actuelle du Rhin supérieur (1 tonne de batteries de voitures par jour); toutefois, la demande régionale en forte croissance devrait à terme porter ce chiffre à 250 tonnes par jour. De plus, le site d'installation de l'usine devra tenir compte des évolutions technologiques du recyclage des batteries qui pourraient nécessiter un espace supplémentaire pour l'expérimentation. Les différentes technologies incluses dans le projet ont des niveaux de préparation technologique et des calendriers distincts. Bien que ce facteur puisse conduire à des synergies potentielles, des interférences ou des dépendances peuvent apparaître et doivent être prises en compte. Certaines technologies pourraient nécessiter des partenaires politiques et industriels au-delà du Rhin supérieur. Par ailleurs, la région du Rhin supérieur dispose de gisements de minéraux importants pour les batteries et nous recommandons de (ré)exploiter ces gisements de ressources primaires, notamment ceux de lithium et de nickel.

Le projet Hydrogène peut bénéficier de quelques potentiels de synergie sur le territoire et pourrait être mis en œuvre sur plusieurs sites pour développer un écosystème de l'hydrogène. Cependant, la principale contrainte réside dans les capacités de production d'électricité limitées localement, ce qui pourrait entraver la capacité de production d'hydrogène basée principalement sur l'électrolyse. L'utilisation des ressources de la biomasse pour produire de l'hydrogène est une alternative intéressante, compatible avec les ressources du territoire, qui mérite d'être approfondie malgré le fait qu'elle soit moins mature que l'électrolyse. Cela vaut également pour d'autres moyens de production innovants (tels que le biogaz, la thermolyse, le craquage thermique) qui sont en cours de développement et qui permettraient de réduire la pression sur les capacités locales de production d'électricité.

Le projet Réseaux Intelligents repose principalement sur l'optimisation énergétique. La «sobriété énergétique» doit également être soulignée pour l'efficacité des réseaux intelligents, car il s'agit probablement de l'approche la plus importante pour construire un réseau électrique résilient et neutre sur le plan climatique.

De manière plus générale, le déploiement rapide de ces projets semble nécessiter: (i) un consensus partagé des acteurs publics et privés concernés et/ou impliqués dans le développement de la filière, (ii) un soutien public significatif et explicite pour limiter les surcoûts liés aux technologies émergentes, (iii) une plus grande participation des acteurs privés notamment dans le partage de l'information qui est cruciale pour une meilleure compréhension des besoins actuels et potentiels afin de développer les installations appropriées, et (iv) une coordination plus explicite avec les politiques publiques aux différents niveaux territoriaux et avec les territoires environnants.

► Cadre juridique

La transformation de Fessenheim en un territoire durable et innovant soulève des questions juridiques liées à l'existence de deux systèmes législatifs, français et allemand, de part et d'autre de la frontière. Il existe des solutions innovantes au sein de ces législations, mais il convient de les identifier et de les appliquer afin de développer ce projet.

La coopération transfrontalière pourrait être la clé pour développer un cadre juridique attractif qui favoriserait la concrétisation du projet. Si des obstacles juridiques devaient être identifiés pour le couplage transfrontalier envisagé de technologies vertes ou la mise en œuvre d'installations spécifiques, etc., la coopération transfrontalière pourrait agir comme un outil juridique permettant aux territoires confrontés aux mêmes problèmes d'expérimenter et de développer des solutions ensemble. Les options juridiques françaises existantes pour les projets innovants pourraient être appliquées et éventuellement étendues à l'Allemagne et vice-versa ou des solutions nouvelles pour les deux pays pourraient être mises en œuvre.

À titre d'illustration, dans le cas de l'hydrogène, par rapport au cadre juridique allemand, l'écosystème français semble être sûr et bien développé étant donné que l'hydrogène est au cœur des stratégies nationales et régionales françaises de transition énergétique (Langstädtler, 2021; Loi 2019-1147, 2019). Actuellement, le cadre juridique français est approprié pour développer des projets pilotes et favoriser les projets innovants (Code de l'Énergie - Livre VIII ; Ordonnance n°2021-167, 2021). Ces innovations permettent d'éventuelles dérogations légales telles que les bacs à sable réglementaires pour faire face aux éventuels obstacles juridiques qui pourraient survenir, s'ils sont éligibles. Les obstacles juridiques n'impliquent qu'une dérogation légale au droit français. Si le besoin s'en fait sentir, une solution intéressante pour un projet transfrontalier confronté à un obstacle juridique pourrait être d'appliquer les règles françaises qui offrent actuellement un cadre juridique plus favorable.

En ce qui concerne les batteries, l'installation d'une unité de production nécessite une autorisation dans les deux systèmes législatifs en raison des préoccupations environnementales (n.d BIMSchG ; n.d Code de l'environnement). Cette procédure longue et coûteuse doit être prise en compte avant toute action concrète. De plus, contrairement à l'Allemagne, il n'existe aucune réglementation spécifique concernant le stockage des batteries en droit français, ce qui constitue un risque juridique sérieux pour le recyclage des batteries. Le lithium étant considéré comme un produit dangereux, il nécessite des moyens de stockage appropriés et un transport réglementé.

Les projets transfrontaliers peuvent bénéficier d'un contexte européen favorable (paquet «Une énergie propre pour tous les Européens», 2019), de sorte que des mécanismes spécifiques de coopération transfrontalière peuvent s'appliquer. La région d'innovation de Fessenheim peut être considérée comme une zone d'innovation bilatérale le long du Rhin. Un tel développement est encouragé par le droit européen de l'énergie (EUR-Lex energy, n.d.) et pourrait faire appel à la clause dérogatoire existant dans le traité d'Aix-la-Chapelle (Traité d'Aix-la-Chapelle - art. 13, 2019). Néanmoins, il existe une limite à la possibilité d'appliquer une dérogation et d'éviter tout dumping normatif: la dérogation doit rigoureusement respecter des règles strictes de protection environnementale et sociale. La clause dérogatoire du traité d'Aix-la-Chapelle reflète également la volonté politique des États français et allemands. En substance, il faut se référer au cadre constitutionnel des États membres comme base juridique impérative.

Dans la plupart des cas, les projets pilotes techniques peuvent être utilisés pour identifier les problèmes et les obstacles juridiques et réglementaires ainsi que pour développer de nouvelles approches juridiques et réglementaires – également au niveau européen – qui sont nécessaires pour étendre les solutions techniques de manière durable.

08. Conclusion

L'étude de faisabilité a démontré que la région d'innovation de Fessenheim est dotée d'un certain nombre d'atouts (voir chapitre 2) qui pourraient l'aider à se développer en un système régional d'innovation transfrontalier européen (CBRIS). Afin d'utiliser efficacement les idées proposées pour son développement, les pilotes sélectionnés doivent être approfondis pour concrétiser et clarifier les idées proposées et pour construire pour chacun d'eux des plans de mise en œuvre distincts. Pour une planification plus détaillée des pilotes ou une sélection de pilotes, un consortium doit être établi avec des parties prenantes

au niveau communal et européen et des partenaires industriels qui possèdent un savoir-faire scientifique et administratif ainsi que des compétences juridiques. Les projets pilotes sélectionnés dans différents domaines peuvent démontrer comment la transformation vers la durabilité est liée aux différents domaines d'innovation technologique. Par exemple, la production d'énergies renouvelables est liée, d'une part, à la capacité de produire de l'hydrogène vert à partir d'électricité et, d'autre part, à des systèmes de réseaux intelligents permettant de distribuer l'électricité de manière optimale et en temps voulu avec

des pertes minimales. Le lien entre la stabilisation du réseau électrique et la capacité de stockage des batteries est tout aussi important, ainsi que le lien entre le stockage des batteries et la nécessité de les recycler pour protéger l'environnement/le climat et réduire la dépendance aux matières premières importées. En gardant à l'esprit les interdépendances, une approche holistique des projets pilotes et de leur mise en œuvre dans une région est essentielle pour comprendre le processus global de transformation vers la durabilité. Le choix de la région du Rhin supérieur et de ses pôles industriels à forte intensité énergétique autour de Bâle, Chalampé et Karlsruhe est un moyen optimal de démontrer les avantages des pôles d'innovation régionaux transfrontaliers en matière de durabilité. En outre, elle offre la possibilité de démontrer, après le démantèlement d'une centrale nucléaire (Fessenheim), comment une région transfrontalière peut être transformée en une région d'innovation prospère et tournée vers l'avenir dans un délai relativement court en réunissant les ressources des deux côtés de la frontière. Avant tout, la réduction de la dépendance aux sources d'énergie fossiles et nucléaires est symbolique pour une région qui a déjà accueilli une centrale nucléaire sur son sol et surtout pour ses citoyens qui ont vécu à proximité de cette centrale et qui sont très attachés à cette question. Par ailleurs, les avantages des pôles transfrontaliers sont nombreux: ils permettent de surmonter les obstacles administratifs et juridiques, de fournir une expertise régionale qui transcende les frontières nationales et d'accélérer le transfert de connaissances entre les entreprises, les sociétés et les organisations scientifiques. Les hubs transfrontaliers augmentent la flexibilité transfrontalière des employés et multiplient les ressources pour des investissements communs. De même, ils font progresser la compréhension interculturelle, rapprochent les visions politiques et renforcent, par des activités communes, la position de l'Europe dans le monde. Un certain nombre d'économistes ont même prouvé que la valeur ajoutée dans les hubs transfrontaliers est très importante (Commission européenne, 2017).

L'étude de faisabilité de la région d'innovation de Fessenheim présente des projets pilotes préliminaires possibles développés sur la base des forces régionales identifiées. L'option la plus réalisable est de mettre en œuvre ces projets pilotes dans la même région, car ils peuvent non seulement fournir des exemples de bonnes pratiques sur la façon dont une transformation innovante vers la durabilité est réalisée, mais aussi démontrer comment les nations des deux côtés d'une frontière peuvent bénéficier d'activités conjointes transfrontalières. Il ressort des différents ateliers de travail avec les partenaires industriels que les projets pilotes proposés sont conformes à leurs plans de développement. Au cours de ces ateliers, les partenaires ont également souligné la nécessité de mettre en œuvre ces projets pilotes dans les délais impartis afin d'ac-

quérir le savoir-faire nécessaire et de les adapter aux installations industrielles. Selon une déclaration de Frans Timmermans, vice-président exécutif chargé du pacte vert pour l'Europe (2022)²: « La transition verte nous libérera de notre dépendance à l'égard des importations d'énergie et d'autres ressources. L'économie circulaire, plus spécifiquement, nous permettra de réduire notre demande en ressources primaires et d'utiliser beaucoup moins d'énergie pour notre production et notre consommation ». Tous les projets pilotes proposés dans l'étude de faisabilité sont conformes à cette déclaration et contribuent à la réalisation de cette exigence. Les pilotes sont détaillés dans le dossier joint à ce document sous la forme de fiche pilote. Ces fiches serviront de base à la concrétisation des idées pilotes. Enfin, la mise en œuvre des projets pilotes nécessite des investissements importants qui doivent être garantis principalement sous forme de fonds de démarrage et de fonds publics, du niveau européen au niveau régional, qui peuvent être utilisés pour affiner et détailler les plans. Des partenariats mixtes public-privé pourraient fournir les investissements requis pour les infrastructures pilotes.

Pour accélérer le processus susmentionné, les prochaines étapes doivent être mises en œuvre dans un délai convenable, conformément aux déclarations des industriels:

1. Formation d'un groupe de gestion chargé de coordonner et d'administrer les activités (y compris les relations publiques) pour la région d'innovation dans le but d'une mise en œuvre pilote.
2. Concrétisation des idées pilotes en détaillant les requêtes de mise en œuvre, comme la compilation des membres de consortiums intéressés provenant de la science et de l'industrie, des administrations et des parties prenantes de la société pour chaque pilote.
3. Elaboration des détails des pilotes et des plans d'exécution.
4. Formation d'un groupe de pilotage pour tous les niveaux de décision liés à la politique, à l'industrie et à la société, ainsi que pour les acteurs régionaux.
5. Formation d'un groupe d'étude du cadre territorial pour accompagner la planification de la mise en œuvre sur les questions environnementales, sociétales et réglementaires.
6. Mise en œuvre d'activités d'approche des investisseurs et d'un plan d'investissement pour les entreprises et les investisseurs publics et privés.
7. Détermination d'une date de début pour les pilotes ainsi que des activités de relations publiques.

² <https://presidence-francaise.consilium.europa.eu/en/news/circular-economy-stakeholder-conference-the-eu-reaffirms-its-ambition-3-03/>

En conclusion, il est impératif que les étapes mentionnées ci-dessus soient exécutées dans des délais brefs. Comme nous l'avons mentionné précédemment, les réactions recueillies à l'issue des ateliers de travail avec les partenaires industriels indiquent que le temps est essentiel pour prendre les devants dans le domaine de l'innovation et créer un impact dans cette décennie.

Références

- Traité d'Aix-la-Chapelle (2019). Traité entre la République française et la République fédérale d'Allemagne sur la coopération et l'intégration franco-allemandes. Disponible sur: https://www.diplomatie.gouv.fr/IMG/pdf/traite.aix-la-chapelle.22.01.2019_cle8d3c8e.pdf
- Bayindir, R., Colak, I., Fulli, G., Demirtas, K. (2016). Technologies et applications des réseaux intelligents. *Revue des énergies renouvelables et durables*. (66), 499-516.
- BlmSchG . n.d. Bundes-Immissions-Schutz-Gesetz Disponible sur: [BlmSchG - nichtamtliches Inhaltsverzeichnis \(en anglais\)](#)
- Bostrom, A, Böhm, G., O'Connor, R.E. (2018). Communiquer les risques: Principes et défis. Dans M. Raue, E. Lerner, & B. Streicher (Eds.), *Psychological Perspectives on Risk and Risk Analysis: Theory, Models, and Applications*. (251-278). Springer.
- Butt, O.M., Zulqarnain, M., Butt, M.T. (2021). Progrès récents dans la technologie des réseaux intelligents: Perspectives d'avenir dans le réseau électrique. *Ain Shams Engineering Journal*, (12) 1. 687-695.
- CalEPA n.d. Lithium-ion Car Battery Recycling Advisory Group. Disponible à l'adresse suivante: <https://calepa.ca.gov/lithium-ion-car-battery-recycling-advisory-group/>
- Paquet « Une énergie propre pour tous les Européens », (2019). Disponible à l'adresse suivante: https://energy.ec.europa.eu/topics/energy-strategy/clean-energy-all-europeans-package_en
- Code de l'environnement. s.d. Disponible sur le site: Code de l'environnement - Légifrance
- Code de l'Énergie - Livre VIII ; Ordonnance n°2021-167 (2021). Ordonnance n° 2021-167 du 17 février 2021 relative à l'hydrogène. Disponible sur: <https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000043148001>
- Cousse, J. (2021). Toujours amoureux de l'énergie solaire? Installation size, affect, and the social acceptance of renewable energy technologies, *Renewable and Sustainable Energy Reviews*, (145), 111107.
- Dühnen, S., Betz, J., Kolek, M., Schmuch, R., Winter, M., Placke, T. (2020). Toward Green Battery Cells: Perspective sur les matériaux et les technologies. *Petites méthodes*. 4. 2000039. 10.1002/smt.202000039.
- DG Mobilité et Transports de la CE. n.d. Consulté le 27.02.2022 sur https://transport.ec.europa.eu/index_en
- Commission européenne (2017). Quantification des effets des obstacles juridiques et administratifs aux frontières dans les régions frontalières terrestres. Rapport final. Disponible en ligne: https://ec.europa.eu/regional_policy/sources/docoffic/2014/boosting_growth/quantif_effect_borders_obstacles.pdf
- Gestionnaires de réseaux de distribution européens (E.DSO) (n.d.). Les gestionnaires de réseaux de distribution (GRD). Disponible à l'adresse suivante: <https://www.edsofsmartgrids.eu/home/why-smart-grid>
- Europa.eu. 2021. Communication de la Commission au Parlement européen, au Conseil, au Comité économique et social européen et au Comité des régions "Fit for 55": delivering the EU's 2030 Climate Target on the way to climate neutrality COM/2021/550. Disponible sur: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0550>
- EU -lex Energy. s.d. Accès au droit de l'Union européenne. Énergie. Disponible à l'adresse suivante: https://eur-lex.europa.eu/summary/chapter/energy.html?root_default=SUM_1_CODED=18
- Fan et al., 2021: Fan, Xiaoping, Chunlei Tan, Yu Li, Zhiqiang Chen, Yahao Li, Youguo Huang, Qichang Pan, Fenghua Zheng, Hongqiang Wang, et Qingyu Li. 2021. In A Green, Efficient, Closed-Loop Direct Regeneration Technology for Reconstructing the Li-Ni0.5Co0.2Mn0.3O2 Cathode Material from Spent Lithium-Ion Batteries. *Journal of Hazardous Materials* 410 (mai): 124610. <https://doi.org/10.1016/j.jhazmat.2020.124610>.
- Institut Fraunhofer pour les systèmes d'énergie solaire-ISE (2020). Agrivoltaïque: Opportunités pour l'agriculture et la transition énergétique. Disponible à l'adresse: <https://www.ise.fraunhofer.de/content/dam/ise/en/documents/publications/studies/APV-Guideline.pdf>
- Boons, F., Montalvo, C., Quist, J., Wagner, M. (2013). Innovation durable, modèles d'entreprise et performance économique: une vue d'ensemble, *Journal of Cleaner Production*, (45), 1-8, <https://doi.org/10.1016/j.jclepro.2012.08.013>.
- Gernaat, D.E.H.J., de Boer, H.S., Daioglou, V. et al. (2021) Author Correction: Climate change impacts on renewable energy supply. *Nat. Clim. Chang.* (11), 362. <https://doi.org/10.1038/s41558-021-01005-w>
- Hafenverwaltung Kehl. 2015. Deutsche Häfen am Oberrhein. Retrieved from: https://www.raonline.ch/pages/edu/st4/wawa_rhein0102a.html
- Harlé P., Kushnir A. R.L., Aichholzer C., Heap M. J., Hehn R., Maurer V., Baud P., Richard A., Genter A. & Düringer P. (2019), Heat Flow Density Estimates in the Upper Rhine Graben Using Laboratory Measurements of Thermal

- Conductivity on Sedimentary Rocks, *Geothermal Energy*, 7 (1): art. 38, <https://doi.org/10.1186/s40517-019-0154-3>
- Harper, G., Sommerville, R., Kendrick, E., Driscoll, L., Slater, P., Stolkin, R., Walton, A., Christensen, P., Heidrich, O., Lambert, S., Abbott, A., Ryder, K.G., Gaines, L., Anderson, P. (2019). Recyclage des batteries lithium-ion des véhicules électriques. *Nature*. 575 (7781), 75-86.
- Hoffrage, U., Garcia-Retamero R. (2018). Améliorer la compréhension des informations numériques pertinentes pour la santé. Dans M. Raue, E. Lerner, & B. Streicher (Eds.), *Psychological Perspectives on Risk and Risk Analysis. Théorie, modèles et applications*. (279-298). Springer.
- Interreg Rhin supérieur (2019). Analyse des Programmes Interreg V OBERRHEIN Endbericht. 11.06.2019. Disponible sur: <https://www.interreg-oberrhein.eu/wp-content/uploads/3-analyse-des-programmgebieten.pdf>
- Jäger T., McKenna R., Fichtner W. (2016). Le potentiel d'énergie éolienne terrestre réalisable dans le Bade-Wurtemberg: A Bottom-up Methodology Considering Socio-Economic Constraints, *Renewable Energy*, (96), 662-675. doi: <https://doi.org/10.1016/j.renene.2016.05.013>.
- Jung, W., Engelke, D., Brester, B., Putlitz, A. 2012. Ulysses: Utilisation des résultats de la recherche appliquée de l'ORATE comme critère pour la planification du développement territorial transfrontalier. Rapport scientifique pour le rapport final Analyse territoriale multithématique de la région métropolitaine trinationale du Rhin supérieur. ESPON & Karlsruhe Institute of Technology. Disponible sur: https://www.espon.eu/sites/default/files/attachments/ULYSSES_Final_Report_-_Scientific_Report_-_CS1_Upper-Rhine_MTA.pdf
- Komiyama, H., Takeuchi, K. (2006). Sustainability science: building a new discipline. *Sustainability Science* 1 (1): 1-6.
- Langstädtler, S. (2021). Brauchen wir ein Wasserstoffinfrastruktur Gesetz ? Zum planungs- und genehmigungsrechtlichen Rahmen für die Erzeugung, Verteilung und Speicherung von grünem Wasserstoff. *ZUR Zeitschrift für Umweltrecht*. 32(4), 203-211.
- Li, X., Zhang, J., Song, D., Song L., Zhang, L. (2017). Régénération directe d'un mélange de matériaux cathodiques recyclés à partir de batteries LiFePO4 mises au rebut. *Journal of Power Sources*. (345). 78-84. doi: <https://doi.org/10.1016/j.jpowsour.2017.01.118>.
- Lopez, A., Roberts, B., Heimiller, D., Blair, N., Porro, G. 2012. U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis. Technical Report NREL/TP-6A20-51946 July 2012. Available online: <https://www.nrel.gov/docs/f12osti/51946.pdf>
- Loi 2019-1147 (2019). LOI n° 2019-1147 du 8 novembre 2019 relative à l'énergie et au climat. Disponible sur: LOI n° 2019-1147 du 8 novembre 2019 relative à l'énergie et au climat - Dossiers législatifs - Légifrance
- Miocic, J. (2021). Stockage de l'hydrogène dans le Fossé du Rhin supérieur. Analyse du potentiel. Rapport Work Package 2.2. Disponible sur: https://www.res-tmo.com/fileadmin/PDFs/Outputs/RES_TMO_Bericht_H2_Speicherung_ORG_EN.pdf
- Mossali, E., Picone, N., Gentilini, L., Rodriguez, O., Manuel Pérez, J., Colledani, M. (2020). Les batteries au lithium-ion vers l'économie circulaire: Une revue de la littérature sur les opportunités et les enjeux des traitements de recyclage. *Journal of Environmental Management*. (264), 110500.
- National Renewable Energy Laboratory n.d. Consulté le 21.02.2022 sur <https://www.nrel.gov/>.
- Neef, C., Schmalz, T., Thielmann, A. (2021). Recycling von Lithium-Ionen-Batterien: und Herausforderungen für den Maschinen- und Anlagenbau Kurzstudie im Auftrag der IMPULS-Stiftung (Stiftung für den Maschinenbau, den Anlagenbau und die Informationstechnik) Recycling of Lithium-Ion Batteries: Opportunities and Challenges for Mechanical and Plant Engineering. Disponible à l'adresse suivante https://publica.fraunhofer.de/eprints/urn_nbn_de_0011-n-6434738.pdf
- Patenaude, J. (2014). Évaluer l'acceptabilité sociale des nouvelles technologies: Lacs et tensions entre science et réglementation. *BioéthiqueOnline*. Disponible sur: https://www.researchgate.net/publication/269573770_Assessing_the_Social_Acceptability_of_New_Technologies_Gaps_and_Tensions_Between_Science_and_Regulation
- Peters, E., Västfjäll, D., Slovic, P., Mertz, C.K., Mazzocco, K., & Dickert, S. (2006). Numeracy and decision making. *Psychological Science*, 17, 407-413.
- Ribon et al. 2018: Ribon B., Badariotti D. et Kahn R. 2018. Fondements des analyses de flux de matières et d'énergie et typologies d'applications pour la gouvernance des territoires et des organisations. *Vertigo - la revue électronique en sciences de l'environnement*, Volume 18 numéro 2. DOI: 10.4000/vertigo.20822
- Regierungspräsidium Freiburg, s.d., Rhin supérieur. Disponible à l'adresse suivante: <https://rp.baden-wuerttemberg.de/rpf/sgz-en/upper-rhine/>
- Samsatl, S., Samsatl, J.N (2019). Le rôle de l'hydrogène renouvelable et du stockage intersaisonnier dans la décarbonisation de la chaleur - Optimisation globale des futures

chaînes de valeur des énergies renouvelables. *Énergie appliquée*, (233-234). 854-893.
<https://doi.org/10.1016/j.apenergy.2018.09.159>.

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

Spangenberg, J. (2011). La science de la durabilité: Une revue, une analyse et quelques leçons empiriques. *Environmental Conservation*, 38(3), 275-287.
doi:10.1017/S0376892911000270

Specht, M., Zuberbühler, U. ; Wittstadt, U. (2004). *Regenerativer Wasserstoff - Erzeugung, Nutzung und Syntheserohstoff*. Stadermann, G.; Forschungsverbund Sonnenenergie -FVS-: Wasserstoff und Brennstoffzellen-Energieforschung im Verbund: Jahrestagung des Forschungsverbunds Sonnenenergie, 25.-26.11.2004 in Berlin. Berlin: FVS, 2005 (Forschungsverbund Sonnenenergie. Themen 2004). S.33-40 Disponible sur le site:
Le Wasserstoff régénéré - Extraction, utilisation et synthèse du Wasserstoff

Tarascon et al., 2021: Tarascon, J.-M. 2021. Batteries: Constituants, Évolution des recherches, Batterie 2030+. Le tout en 5 min. Webinar, 13 avril. <https://www.concer-tation-acc-batteries.fr/compte-rendu-et-replay/7>.

La Conférence du Rhin supérieur. (2020). Brochure statistique de l'Oberrhein. Récupéré de: https://www.ober-rheinkonferenz.org/de/statistik/downloads.html?file=files/assets/ORK/docs_de/allgemein/broschueren/statisikbro-schuere-oberrhein-2020.pdf&cid=2792