SUMMARY REPORT

Feasibility Study Innovation Region Fessenheim 2021 – 2022

Edited by Barbara Koch

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Preamble

The project on the future of the Fessenheim region, adopted in 2019, pursues the "common goal of becoming a European region for low-carbon economy based on excellence and innovation, these creating jobs and adding value, and in which citizens, companies and stakeholders from research and institutions participate".

Against this backdrop, the French State, the Grand Est Region, the German Federal Republic and the Federal State Baden-Württemberg supported the "Innovation Region Fessenheim" feasibility study.

The study was carried out by the European Groupings of Territorial Cooperation (EGTCs) Eucor - The European Campus and in coordination with the Upper Rhine Cluster for Sustainability Research.

The French State, the Grand Est Region, the German Federal Republic and the Federal State Baden-Württemberg would like to thank all the scientific teams for carrying out this far-reaching project as well as the economic actors for their contributions. They recognise the great value of the multidisciplinary work done within the last 18 months.

The study, recommendations and pilot projects described are the result of expert cooperation. These will be presented to the decision makers, funding partners of the study, yet are not binding in nature for the French State, the Grand Est Region, the German Federal Republic or the Federal State Baden-Württemberg. They form the basis for further potential future discussions between the institutions and partners of the Upper Rhine region. In accordance with the political guidelines of the respective funding partners, the conclusions of the study can, in conjunction with the business world, contribute to the transformation of the Fessenheim region.

French Republic

La préfète

Josiane CHEVALIER

Josiane CHEVALIER
Prefect of Grand Est Region, Prefect of Bas-Rhin

Grand Est Region

Jean ROTTNER
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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).

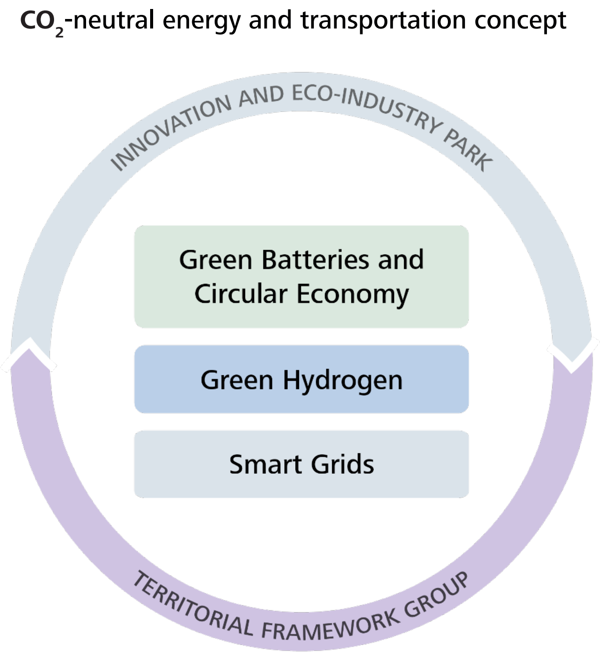

Figure 1. Innovation fields for the development of best practice examples embedded in territorial framework conditions and located in innovation and eco-industry parcs

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). Aptly, 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 CO_2 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 (Rhone 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 CO_2-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).

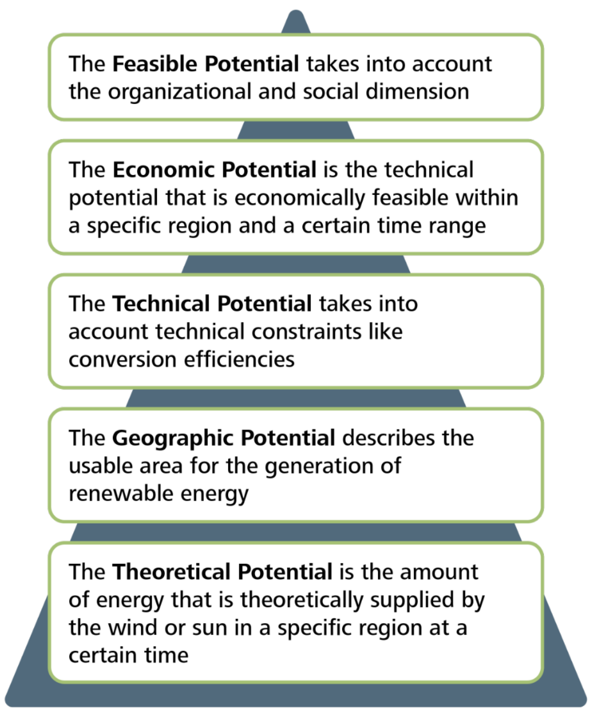

Figure 2: The Potential Hierarchy as defined by Jäger et al. (2016) and adapted in the RES-TMO Project

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 subcategories 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.

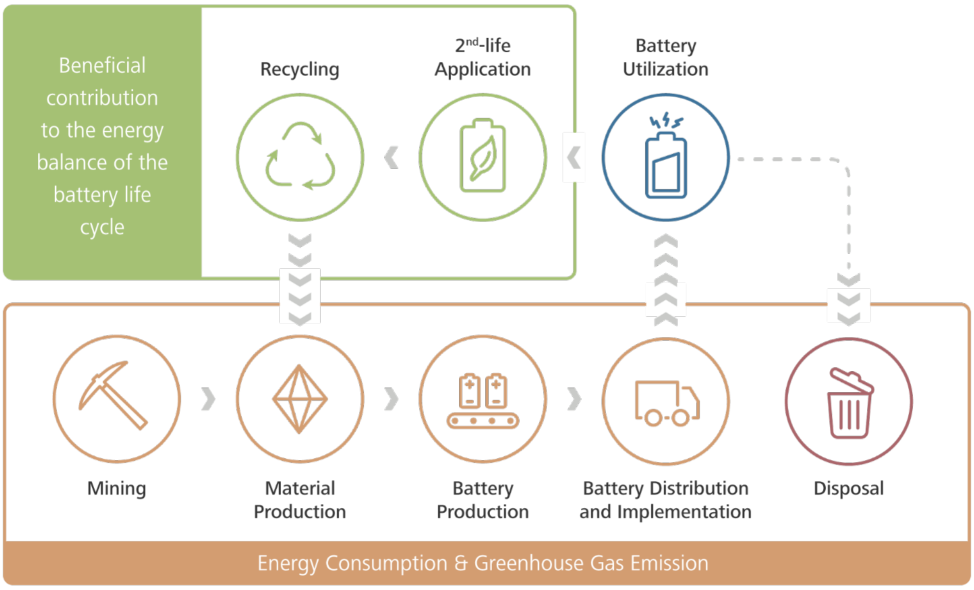

Figure 3: Lifecycle of a battery (Dühnen et al., 2020)

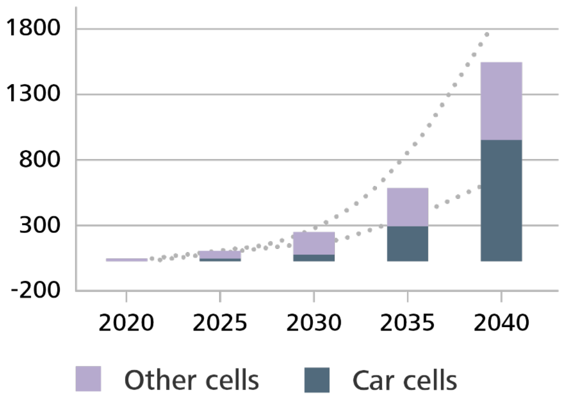

Figure 4: Prognose about the LIBs recycle flow in kt (high and low) till 2040 (Adapted from Neef et al., 2021)

[1] The 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.

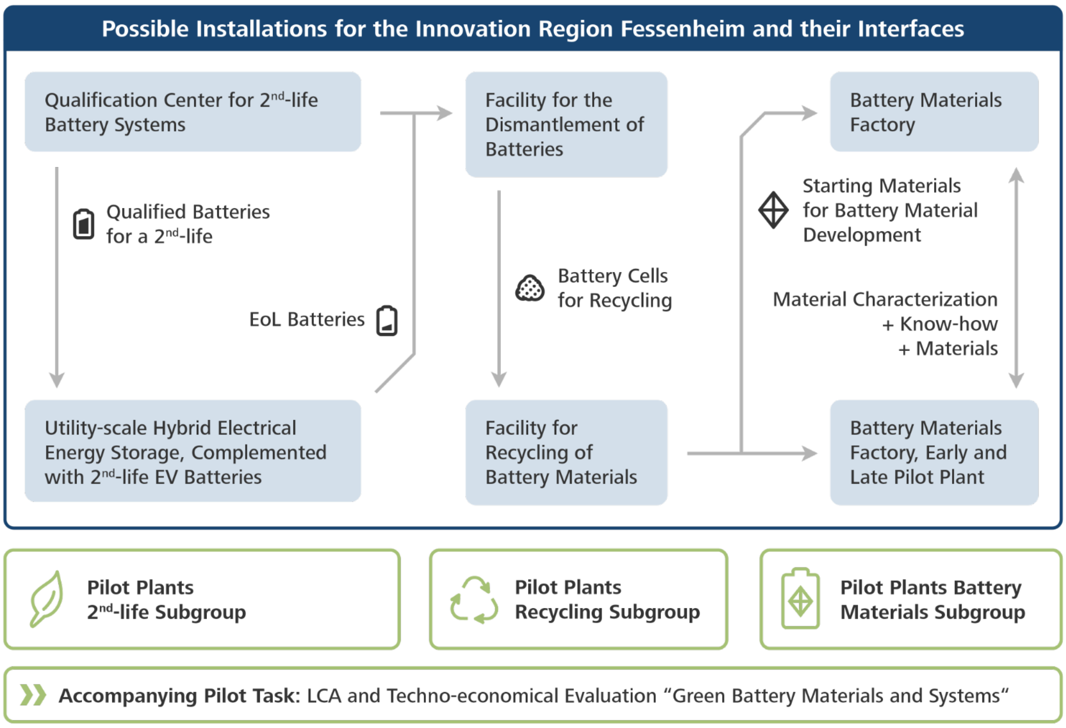

Figure 5: Main pilot scheme suggested by the battery competence group

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 CO_2-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.

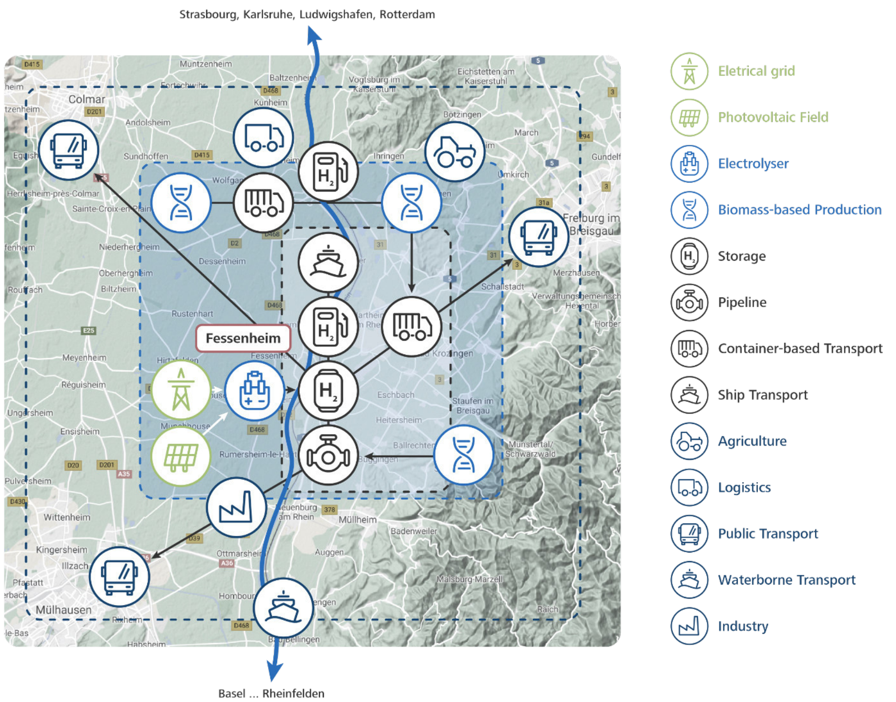

Figure 6: Main elements of the Multi-Modal Hydrogen Hub in the Fessenheim region

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 tri-modal 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 concept 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 CO_2 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.

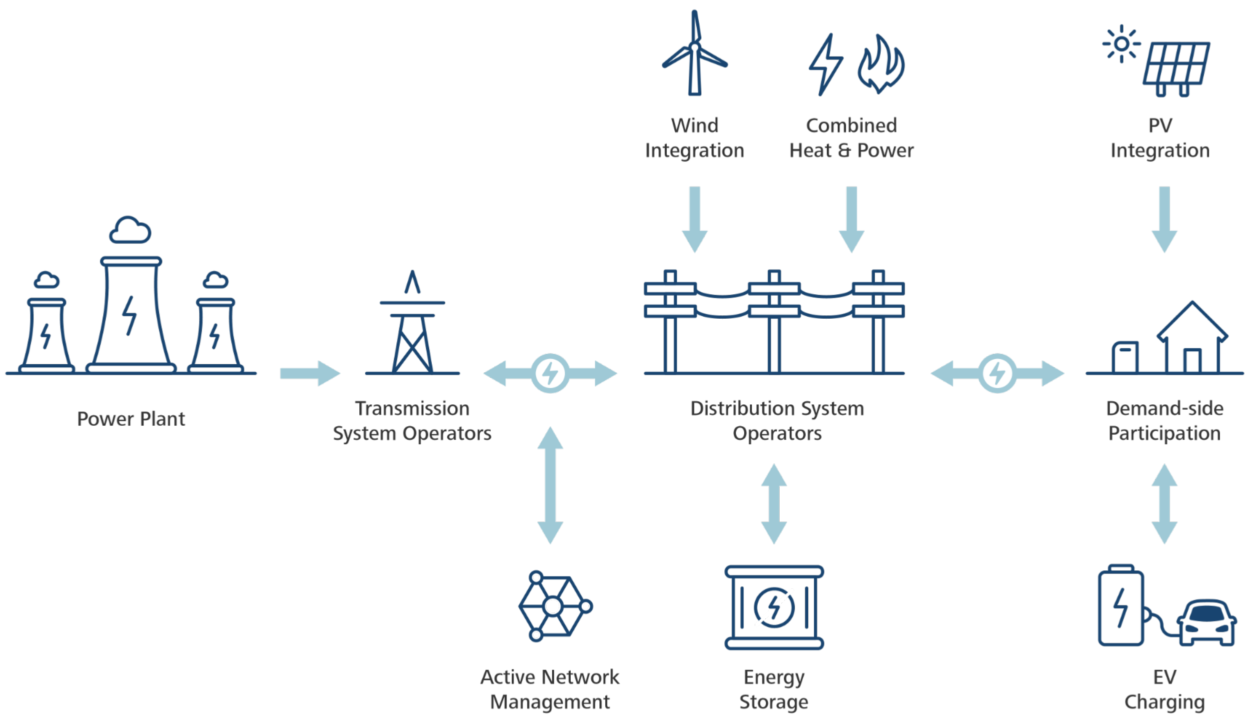

Figure 7: A possible testbed for a smart grid system in the quartier pilots

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.

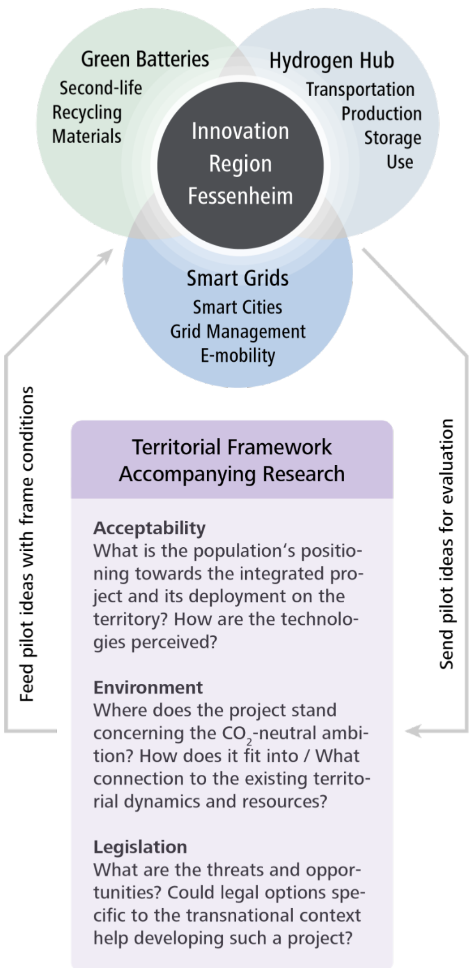

Figure 8: The Interconnection of the Territorial Framework group and the other competence groups.

Recommendations

► Social acceptability

Social acceptability of new innovations is crucial (Patenaude, 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 technological 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 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.

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 BIMSchG; 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 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 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 Timmermanns, 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/

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