TRANSIENCE

TRANSITIONING TOWARDS AN EFFICIENT, CARBON-NEUTRAL CIRCULAR EUROPEAN INDUSTRY

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D2.2 – Assessing Needs for Model Applications

WP2 – Understanding Stakeholder Needs for New Capacities

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Responsible Author	Lukas Hermwille	Email	lukas.hermwille@wupperinst.org		
	WI	Phone	+49 202 2492 284		
Contributors	Iñigo Muñoz, Diego García-Gusano, Izaskun Jiménez, Hanna Kuittinen [TECNALIA]; Miriam Ruß [WI]; Gergő Sütő, Li Shen, Ernst Worrell [UU]; Agnieska Zięcina, Arkadiusz Kocaj, Patryk Białas [PNTEC]				
Reviewer(s)	Georgios Xexakis [HOL]; Natasha Frilingou, Alexandros Nikas [ICCS]; Panagiotis Fragkos [E3M]; Iñigo Muñoz [TECNALIA]				
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EC Summary Requirements

1. Changes with respect to the DoA

The deliverable does not deviate from the work described in the DoA. However, the methodological approach for the Port of Rotterdam case study constitutes an adaptation to the work carried out in all other case studies; due to a large number of workshops previously held in the region, the responsible researchers were unable to secure adequate interest for a stakeholder workshop and instead reverted to a series of interviews. Although the deliverable was submitted in October 2024, in line with the DoA deadlines, a *slightly* updated version was submitted in January 2025, to properly document the EU-wide stakeholder workshop that was held a few days prior to the deliverable's original submission as well as to streamline overview tables and causal loop diagrams across all case studies.

2. Dissemination and uptake

This deliverable is meant to shed light on the barriers and enablers of the industrial decarbonisation and circularity transition in four regional case studies. This is meant to inform modellers within the project about potential knowledge gaps that could be answered during the TRANSIENCE project.

3. Short summary of results

This report presents the results of the initial stakeholder engagement phase, focusing on identifying key transformation challenges and research capacity needs in four industrial regions: the Basque Country, Rhine-Ruhr Area, Port of Rotterdam, and Silesia. The Three Horizons dialogue facilitation method was used to elucidate the specific barriers and enablers for transformation. Based on the insights from the workshops, common stakeholder needs were formulated that could potentially be answered by the models developed in TRANSIENCE. Insights and perspectives from an EU-level stakeholder workshop, held jointly with the sister project AMIGDALA, are also included and discussed. Eventually, we come up with 10 key takeaways revolving around resilience of sustainable pathways to price/supply-chain shocks, the costs of economic resilience, the effects of circularity performance on resilience and competitiveness, the prioritisation of public investments, socioeconomic impacts of transformation, the development pace of green markets, locational advantages of industrial clustering, impacts on fossil fuel-reliant regions, trade-offs and co-benefits of symbiosis, and interdependencies between green feedstocks for chemicals vis-à-vis other energy uses.

4. Evidence of accomplishment

This report.

Preface

The need to approach climate action, resource efficiency, and circularity performance as integrated, economy-wide, cross-cutting issues is growingly gaining attention in the policy world, stimulating the development of new industrial policies in Europe and worldwide. Currently, however, there is little progress in conceptualising the circular economy and understanding its interactions with climate action. State-of-the-art modelling capacity to capture the interplay of the two agendas and their implications for energy-intensive sectors as well as to represent the European industry's transformation in line with the region's vision for climate neutrality is not yet fully developed. TRANSIENCE will undertake a comprehensive characterisation and assessment of circularity principles and measures vis-à-vis decarbonisation, by looking at the twin transition of European industries through the lenses of global competitiveness, innovation, and holistic sustainability. It will then produce MIC3, a consistent, fully open-source model ecosystem to assess industrial circularity, decarbonisation, and sustainability. A series of interoperable modules on the socioeconomic, service and product, material, industrial, energy-system, and environmental perspectives of the transformation of European industry will be developed and integrated, building on and opening the code of leading modelling tools. MIC3 will finally be used in extensive scenario modelling to produce diverse pathways toward a material-efficient, circular, climate-neutral, sustainable European industry. Transparency, openness, and knowledge sharing will be promoted, and technical capacities will be developed in four industrial agglomerations in the EU, moving beyond stakeholder consultation, onto model co-development, continuous validation of assumptions, co-creation of scenario modelling, evaluation of the desirability and usability of the developed model and insights, and eventually co-production of science and action.

ICCS – Institute of Communication and Computer Systems	EL
CEPS – Centre for European Policy Studies	BE
E3M – E3-Modelling AE	EL
Fraunhofer – Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V.	DE
HOL – HOLISTIC IKE	EL
PIK – Potsdam Institut für Klimafolgenforschung e.V.	DE
PNTEC – Park Naukowo-Technologiczny Euro-Centrum Spolka Z Ograniczona Odpowiedzialnoscia	PL
TECNALIA – Fundación Tecnalia Research & Innovation	ES
UU – Universiteit Utrecht	NL
WI – Wuppertal Institut für Klima, Umwelt, Energie gGmbH	DE
PSI – Paul Scherrer Institut	CH
UCL – University College London	UK

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Executive Summary

This report examines the key transformation challenges and research capacity needs in four European industrial regions: the Basque Country, Rhine-Ruhr Area, the Port of Rotterdam, and Silesia. The study employed a mixed methods approach, including desk research and stakeholder workshops utilising the Three Horizons facilitation method. In three regions, workshops involving 8-18 participants representing diverse stakeholder groups were held. Due to prior workshop saturation, the Port of Rotterdam study opted for a series of interviews, drawing insights from well-documented previous workshops.

A key finding across all regions is the heightened perception of risk and uncertainty stemming from recent global events. This uncertainty affects various dimensions, including technology choices, geopolitical stability, resource availability, and political landscapes, exacerbating an investment bottleneck as industries face reinvestment decisions against a backdrop of strained public finances and volatile interest rates. This uncertainty is compounded by the lack of a clear business case for green materials despite the anticipated decline in the viability of traditional, emission-intensive materials within the EU. While interest in green materials exists, uncertainties around certification, bulk availability, and production costs make securing financing for green production facilities challenging.

The changing landscape of industrial geopolitics is a major concern for stakeholders, particularly in export-oriented regions like Rhine-Ruhr and the Port of Rotterdam. Competition from China, coupled with substantial subsidies offered by China and the United States, raises concerns about the EU's ability to provide a comparable playing field for its industries. Concerns also extend to the security of critical raw material supplies in the event of geopolitical conflict escalation. Establishing a circular economy within Europe is viewed as a potential mitigation strategy to address resource dependencies, but its feasibility and impact on economic resilience remain open questions.

The transition towards a circular economy faces complexities arising from the need to implement a range of "r-strategies" beyond recycling. While higher-level strategies like remanufacturing and product lifespan extension (reuse, repair) offer promise, their potential impact on primary production and decarbonisation remains largely unexplored, especially in the context of model-based scenario analyses. Determining the appropriate level for closing material loops, whether local, national, European, or global, further complicates the circularity transition. These challenges are particularly pronounced in the chemical industry, where chemical recycling presents a potential alternative to fossil fuel feedstocks, but faces practical hurdles related to feedstock availability, infrastructure requirements, and spatial constraints, as highlighted in the Port of Rotterdam case study.

Across all regions, investment in technological infrastructure is deemed crucial for accelerating decarbonisation. The need for electricity grid expansion to accommodate industrial electrification as well as a robust hydrogen infrastructure are paramount. While the Port of Rotterdam has ongoing decarbonisation infrastructure projects, including hydrogen, CCS, and biorefineries, substantial further investments are required to adapt existing fossil-fuel based infrastructure to handle renewable feedstocks. Silesia, undergoing a transformation from a coal-based energy system, requires substantial infrastructure funding, while the potential growth of its recycling industry hinges on investments in recycling technologies and infrastructure.

Spatial constraints pose a significant challenge, particularly in the Basque Country and Port of Rotterdam, where densely packed industrial zones limit infrastructure expansion for both decarbonisation and

circularity initiatives. Conversely, these densely populated industrial areas also present opportunities for enhancing industrial symbiosis and circularity by leveraging geographical proximity and material flow synergies. Silesia, with its abundance of brownfield sites, sees potential for repurposing existing infrastructure for greener investments, although site rehabilitation and land pollution issues present additional challenges.

The social dimension of the industrial transition is a key consideration. Ensuring a just transition that encompasses workers and communities is crucial. Social acceptance of decarbonisation and circularity solutions needs careful evaluation. Policy recommendations include public programs for upskilling and reskilling workers from declining industries, particularly in regions like Silesia heavily reliant on coal mining, and targeted support for Small and Midsize Enterprises (SMEs) facing adaptation challenges. The report concludes by distilling a set of research questions, amenable to model-based scenario analysis, aimed at addressing the challenges and uncertainties identified by stakeholders and guiding investment decisions towards a more sustainable and resilient European industrial future:

- How resilient are decarbonisation pathways and strategies against drastic price shocks or supply chain disruptions?
- What are the costs of economic resilience and how can we measure it?
- Which effect can circular economy strategies have in enhancing resilience and competitiveness of EU industries?
- Which public investments are key and need to be prioritised? And can we design decarbonisation pathways that minimise (public) investments?
- What are potential socio-economic impacts (incl. distributive and health impacts) of different decarbonisation and circularity solutions on social acceptance and consumption patterns?
- How fast are markets for green raw materials going to develop under a variety of policy measures to support green lead markets?
- How potent are locational advantages of clustering vis-à-vis locational disadvantages related to limited availability and comparatively high cost of energy supply (RE and hydrogen)?
- What is the impact of different decarbonisation infrastructure investment strategies on emissions reduction, economic competitiveness, and energy security in regions heavily reliant on fossil fuels?
- What are trade-offs between spatial limitations, which can hinder large-scale infrastructure development, and the potential benefits of geographical proximity for fostering industrial symbiosis and circularity?
- What are the interdependencies and trade-offs between green feedstocks for chemicals (circular/renewable carbon or biogenic carbon) vis-à-vis other energy uses?

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1 Introduction

In its recent 6th Assessment Report the Intergovernmental Panel on Climate Change (IPCC) has stipulated that a broader societal transformation is necessary to achieve the Paris goals in a fair and just manner. The TRANSIENCE project has set out to develop a new suit of quantitative models to enable scenario-based analyses to better understand current sources and future trends of emissions and the policy and technology options to mitigate them. Although there has been much debate on the prospect of studying the broader socio-political context of sustainability transitions within models (Trutnevyte et al., 2019), participatory modelling has received much less attention. The merits of co-creative, transdisciplinary modelling science are several: it helps integrate a more diverse range of perspectives (Lang et al., 2012), identify concrete needs or blind spots (Süsser et al., 2022), build ownership of problems/solutions and consensus on how to proceed (Waisman et al., 2019), develop policy-, industry-relevant, actionable solutions to the complex real-world problems (Fazey et al., 2018), enhance the legitimacy and validity of the results (McGookin et al., 2021), and make models more useful towards achieving greater policy impact (Süsser et al., 2021). Despite these benefits, recent reviews have noted that the commonly employed participation modes remain very focused on top-down approaches, without offering the opportunity to stakeholders to truly affect and validate modelling outcomes (Galende-Sánchez & Sorman, 2021).

The TRANSIENCE project set out to address this issue with transdisciplinary ambition: "(a) to grasp the relevant complexity of a problem (b) to take into account the diversity of life-world and scientific perceptions of problems, (c) to link abstract and case-specific knowledge, and (d) develop knowledge and practices that promote what is perceived to be the common good" (Hirsch Hadorn et al., 2008, p. 4). This report addresses the first two of these aspects. It reflects on the results of the first phase of stakeholder engagement with the aim of identifying jointly with relevant stakeholders the research capacity needs in terms of ongoing and future transformation trends, for which modelling can provide useful insights.

A key challenge of this task is that stakeholders from industry, government and civil society may be familiar with reading scenario-based analyses but are typically much less familiar with the underlying modelling tools and typically cannot specify concrete 'user needs' by themselves. To circumvent this problem this report starts out by charting key transformation challenges (technical/infrastructure, political/institutional, economic, capacity/awareness) and vantage points where the new modelling tools may generate insights to address those challenges. On this basis we develop qualitative systemic insights – where appropriate, formalised in qualitative dynamic system models in the form of causal loop diagrams – which can then be discussed with the modelling community to formulate concrete design requirements for the new models to be developed later in the project.

To achieve this, we conducted stakeholder engagement processes in four key industrial regions: the Basque Country in Spain, the Rhine-Ruhr Area in Germany, the Port of Rotterdam industrial region in the Netherlands and Silesia in Poland. We focus on regional level stakeholder engagement because energy-intensive industries are in many cases concentrated geographically, as is the case in all four case study regions. Heavy industries form large clusters that typically emerge where there is a critical mass of related companies and institutions, and favourable economic, social, cultural conditions supporting collaboration and innovation. They create networks of firms that produce similar or complementary products or services, including specialised suppliers, service providers, research institutions, and other organisations supporting the industry. This proximity of firms and institutions has historically created synergies, facilitated the use of industrial by-products whose long-distance transport would not have been economically viable, and enabled substantial incremental innovation. But the high degree of integration across such firms may also create path dependencies inhibiting more disruptive innovation, as required to achieve decarbonisation and circularity (Janipour et al., 2022).

A place-based approach provides conceptual and methodological tools for contributing to guiding industrial decarbonisation in ways that are grounded in the social sciences; it can also assist with joining up diverse policy goals: mitigating climate change, enabling economic prosperity, and reducing regional inequalities (Devine-Wright, 2022). Hence, any actions to facilitate decarbonisation and promote circularity performance must account for the physical reality of industrial clusters and their synergies and interdependencies. In turn, to be most useful, modelling tools must also be designed to reflect the reality of such clusters and produce results that are informative to their transformation challenges.

The four regions were strategically selected to cover a wide range of industries as well as political, climate policy, and socioeconomic contexts. This aligns with our intention to represent sub-national spatial resolution in MIC3, allowing for relatively efficient model application without excessive additional data requirements, and providing site-specific information that helps understand interactions between sites within the clusters. These four regions were also selected as several consortium partners have established networks of industrial stakeholders within them, built in previous and ongoing research activities and serving as a foundation of and prerequisite to successful deep transdisciplinary collaboration.

To complement our four regional stakeholder engagement strategies, we organised an interactive workshop in Brussels in collaboration with the AMIGDALA project.[1] This workshop brought together political, industrial, and scientific stakeholders at the European level to discuss key knowledge gaps and uncertainties surrounding industrial transformation, which were identified in the two projects. In partnership with AMIGDALA, four breakout sessions were facilitated, each focusing on a distinct thematic area (see annex).

[1] https://amigdalaproject.eu/

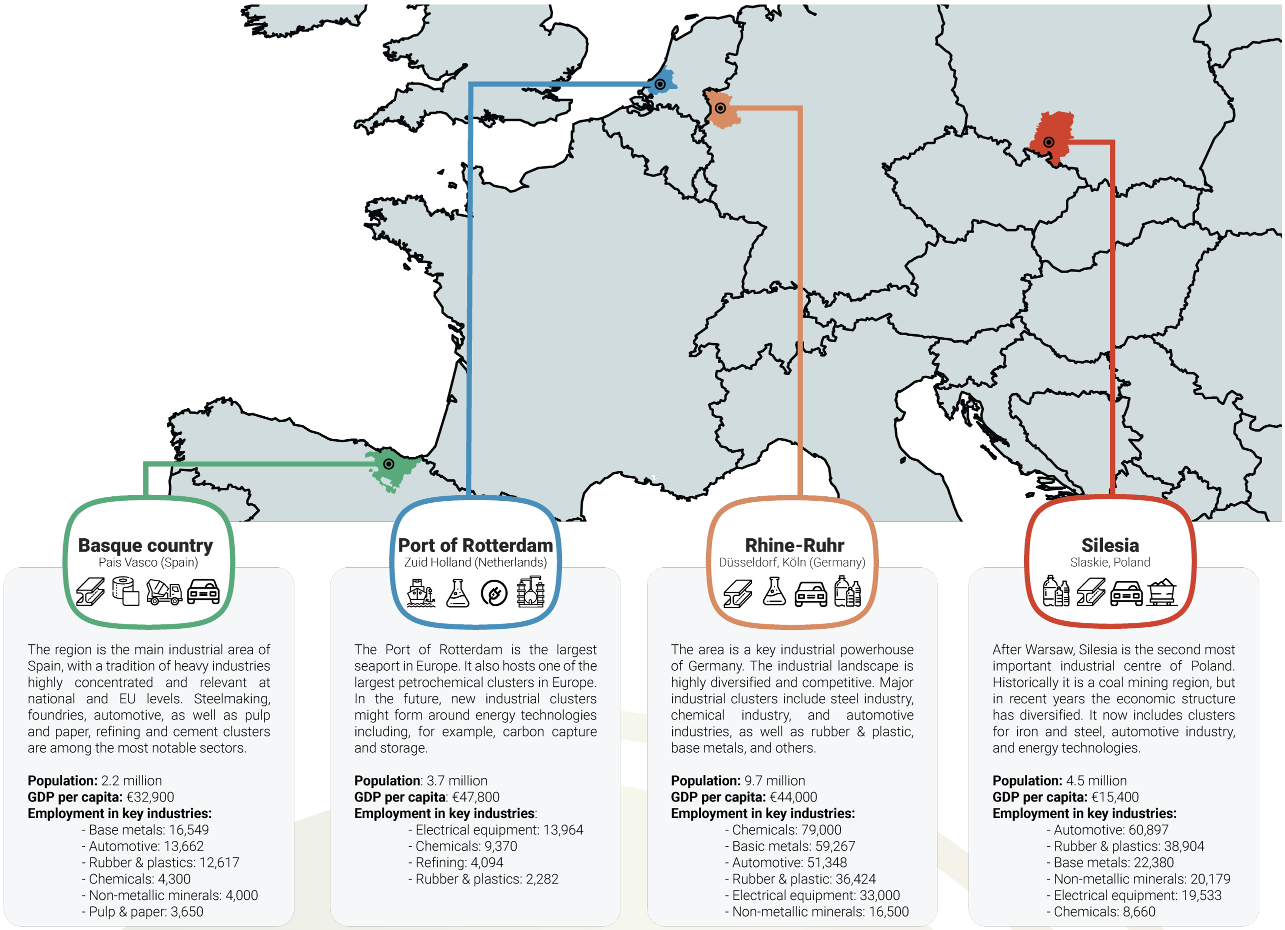

Figure 1. **Scope and socioeconomic background of the four industrial cluster case studies in TRANSIENCE.**

Table 1. **Overview of key socio-economic variables. Note: Heavy industry includes basic metals, manufacture of chemicals and non-metallic minerals. The share of the employment in the corresponding industry national total employment was used as a proxy to estimate the GVA attributed to the corresponding region. Source: Eurostat.**

Region	Rhine-Ruhr	Basque Country	Silesia	South Holland
NUTS2 Codes	***DEA1, DEA2***	***ES21***	***PL22***	***NL33***
Population	9,686,304	2,189,138	4,475,460	3,744,299
Employment (total)	4,418,900	907,700	1,810,400	1,844,800
Employment (heavy industry)	154,799	24,849	51,218	13,364
Regional GDP [in Billion EUR]	405.74	66.42	61.40	167.11
Gross Value Added (heavy industry) [in Billion EUR]	14.024	1.718	3.802	1.986

This report provides a synthesis of the insights generated by the four stakeholder processes. The four individual case study reports, as well as a report of the Brussels workshop, are provided as an annex. In section 2, we first introduce the method employed to engage stakeholders. Section 3 presents the results in the form of six key thematic areas that have been identified as common challenges affecting all regions, albeit to varying degrees. Section 4 concludes by highlighting potential avenues for enhanced modelling and scenario analyses which can serve as the foundation for specifying design requirements for subsequent model development.

2 Method

2.1 Regional case studies

The four case studies implemented a mixed methods approach. In a first step each research team surveyed the existing literature including academic journals, "grey" research reports commissioned for example by government, NGOs or industry associations as well as relevant government strategies and planning documents. This desk research phase served two purposes: to develop a basic understanding of the key transformation drivers and barriers applicable in each region and to gain an overview of the type and scale of scenario modelling that has already been employed to support transformation processes in the regions.

Table 2. Key information on regional stakeholder workshops.

Basque Country	Rhine-Ruhr	Silesia
Date: 28 May 2024	28 August 2024	18 September 2024
Place: TECNALIA offices, Zamudio, Basque Country, Spain	Place: Wuppertal Institute, Wuppertal, North Rhine-Westphalia, Germany	Place: EURO-CENTRUM Science & Technology Park, Katowice, Poland
10 Participants including representatives of regional energy agency, regional environmental agency, regional energy cluster, regional environmental cluster, energy-related think tank, climate change research centre, universities.	8 Participants including representatives of regional energy agency, steel industry association, trade unions, environmental NGO, industry (industrial gases), research organisations.	18 participants including representatives of from national and regional government authorities, business environment institutions, research organisations and universities, private enterprises, and environmental NGOs.

The second methodological strand of the research related to stakeholder engagement. We held regional stakeholder workshops with 8-18 participants covering a range of different stakeholder types in three of the four regions. Despite numerous attempts the team in charge of the Port of Rotterdam case study was unable to recruit a minimum required number of stakeholders and instead reverted to a series of interviews instead. The reason for not implementing the originally planned approach was due to a "workshop fatigue" on the part of key industrial stakeholders after a series of similar workshops had been held in the region in the recent past. On the other hand, many of these workshops are well-documented enabling the researchers to draw on the published outcomes instead.[2]

A challenge for all four regional case studies was the identification of key stakeholders in each region. While some regions including the Basque Country, the Rhine-Ruhr area and the Port of Rotterdam have established networks and/or platforms for industrial stakeholder engagement, no comparable network exists in Silesia requiring a more labour-intensive approach.

For the Rhine-Ruhr case study, participants were recruited via the IN4Climate.NRW platform. IN4climate.NRW is a unique platform in Germany that brings together industry, academia, and policymakers to develop innovative strategies for a climate-neutral industry. Given the high CO2 emissions of the industrial sector in North Rhine-Westphalia, the initiative aims to create new production processes, infrastructures, and frameworks. Through close cooperation between companies, research institutions, and the state government, concrete measures are being developed for climate-neutral production. IN4climate.NRW acts as a think tank that promotes not only strategic guidelines but also concrete implementation projects. The initiative is divided into various working groups that deal with topics such as hydrogen, carbon, and raw

[2] see case study Rotterdam in the Annex for a more detailed justification for the alternative methodological approach.

materials. The goal is to make North Rhine-Westphalia a leading location for a sustainable and competitive industry. The Wuppertal Institute is strongly involved in this initiative and coordinates the accompanying scientific research project. Participants for the workshop were recruited from the group of active participants of IN4Climate.NRW and included the platform's coordinators.

In the case of the Basque Country, the participants were selected through TECNALIA's contacts with relevant regional stakeholders. As member of the *Basque Net Zero Industrial Super Cluster* (NZBIS)[3], TECNALIA identified and got in touch with policymakers, industrial associations, academia and research organisations working on the decarbonisation and circularity of the Basque industries. The recruitment of the workshop participants was conducted through personal contacts and individual interviews with the selected stakeholders in order to present the objectives of the project and engage them, not only in the first workshop but also in the different participatory activities to be conducted throughout the TRANSIENCE project.

As stated above, no similar networks exist in Silesia. The Silesian team therefore had to revert to a more elaborate stakeholder mapping and selection method.[4] Initially, industries were categorised based on available statistical data. To determine the significance of each industry in the region, sixteen indicators were employed, covering quantitative aspects, industry efficiency, and environmental performance. A comprehensive database of potential stakeholders was then created, encompassing industrial companies, decision-makers, organisations, associations, and research units. To assess stakeholder involvement and influence, a power-interest matrix was utilised. This matrix allowed for the visualisation of stakeholder positions and the identification of potential areas of collaboration and conflict. The final step involved selecting the most influential stakeholders based on the mapping results, considering their potential impact on the project's success. Through this multi-step process, the strategy provided a clear and structured approach to identifying and prioritising stakeholders, ensuring that their perspectives and needs were adequately considered throughout the project's development.

All three stakeholder workshops utilised the Three Horizons facilitation method to engage participants. The Three Horizons Dialogue framework (Sharpe et al., 2016) is a tool to engage a diverse group of stakeholders in a structured collective imagining/visioning exercise. Its key strength is to integrate diverse perspectives and to enable a constructive way forward even when competing or contradicting views are assembled in the group. The method is particularly useful as a brainstorming tool for initiating a conversation among a group of participants coming together for the first time. It enables the group to quickly establish a common ground from which decisions for the direction of future deliberations can be taken. However, it can also be used in a more in-depth way, guiding an entire scenario-development workshop.

[3] https://www.spri.eus/es/ayudas/net-zero-basque-industrial-super-cluster/
[4] see annex for a detailed description of the strategy.

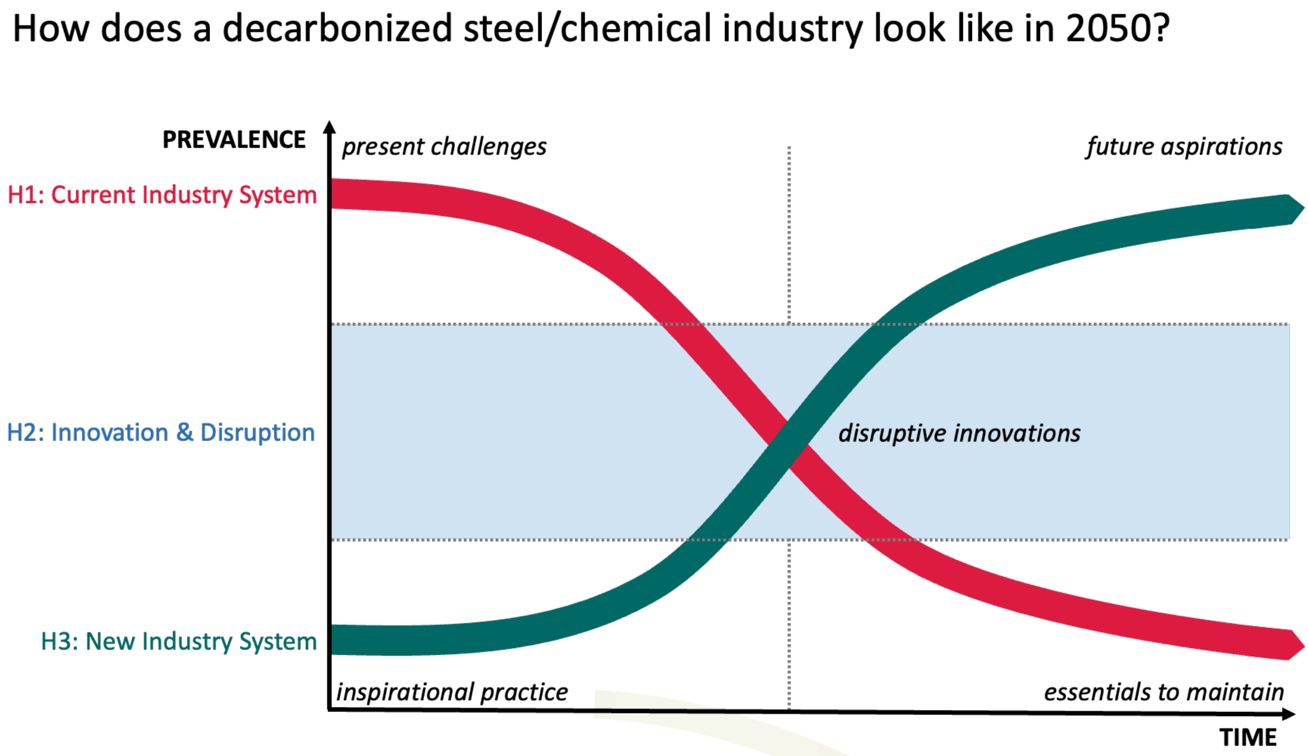

Figure 2. The Three Horizons Dialogue Framework key figure. Adapted from Sharpe et al. (2016).

The Three Horizons Method structures the conversation using a chart illustrating the imminent structural changes (see figure above). This chart contains three "horizons". The first horizon (H1) focusses on a diagnostic of the state of play of the (unsustainable) current socio-technical system. It represents the way things are done now, generally called "business as usual." H1 patterns are starting to lose fit with emerging conditions for example due to the need to decarbonise in the light of increasing climate change impacts but also changing industrial geopolitics. This corresponds to 'system knowledge'. "Keeping the lights on" in the current system requires a management perspective. The third horizon (H3), in turn, focusses on the future climate neutral and circular industrial system that stakeholders envision collectively. H3 represents the emerging pattern that will be the long-term successor to the current first horizon. It is appearing and growing on the fringes of the present system. This corresponds to 'target knowledge'. Imagining the third horizon requires a visionary mindset. Finally, the second horizon (H2) represents the turbulent domain of transitional activities and innovations that people are trying out in response to the changing landscape between the first and third horizons. This corresponds to 'transformation knowledge'. Bringing new ideas and innovations into reality requires entrepreneurial spirit.

During the workshop, participants were invited to populate the three horizons chart by writing down their comments/insights on post-its or paper cards and placing them on the corresponding quadrant of the chart. This was done in three rounds each focussing on one of the three horizons. In all three workshops, the method worked well and sparked an interesting and engaged debate among the participants.

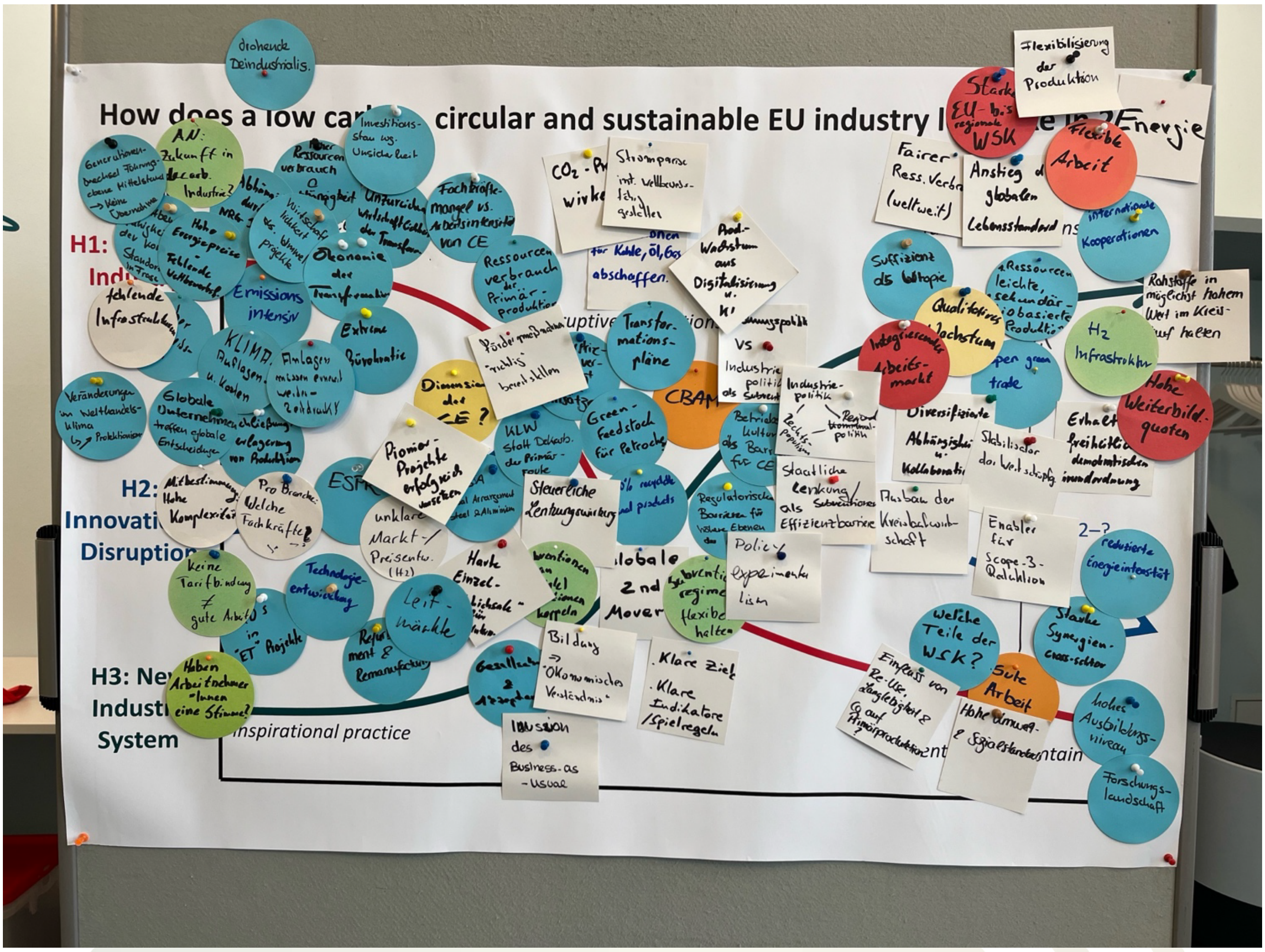

Figure 3. Result of the Rhine-Ruhr regional stakeholder workshop.

After the stakeholder workshops were concluded, the next step was to organise the arguments and insights collected from stakeholders into thematic clusters and establishing causal relationships between them. This was done by, first, consolidating and merging similar concepts and including them in a causal relationship table. For each of the concepts included in the three horizons chart, it was established whether it constitutes a cause or an effect, whether it is related to any of the other concepts, and – if possible, whether the effect is positive or negative. This was done taking into account comments made by the participants during the workshop but also the researchers own expert knowledge, and the insights gained from the desk research conducted in the first phase.

Next, we started to build a first version of a causal loop diagram utilising the free open-source online tool "insightmaker".[5] The first iterations yielded very messy representations of the causal relationships. In an iterative process we created increasingly more organised versions by removing unnecessary detail, simplifying and merging concepts as appropriate, and identifying causal loops in the process. Once the main causal loops were identified, we created simplified versions representing selected aspects or challenges taking into account the priorities and main concerns expressed by participants during the workshop. As a final step, a synthesis of the insights of each workshop as well as draft versions of the causal loop diagram were sent to selected participants for comments.

[5] https://insightmaker.com/

2.2 EU-level Stakeholder Perspectives

As the Brussels stakeholder workshop was conducted in collaboration with the AMIGDALA project and based on the results of the case studies, a different approach was used. Stakeholders were invited to participate in four breakout sessions, each focusing on a different topic. To encourage cross-pollination of ideas, participants had the opportunity to switch groups halfway through the session. Furthermore, the second group could then build on the ideas and inputs of the first group.

The following four topics were chosen for the breakout sessions:

- Political dynamics as a transformation barrier and the role of EU ambition & leadership
- Technological challenges and solutions for a low-carbon and circular European industry
- Business opportunities for global industries to operationalise the green transition
- Key uncertainties for policymakers and for businesses of the basic industry

In the first session, the Causal Loop Diagram which was created based on the insights of the Rhine-Ruhr area and dealing with the relationship between political dynamics and green investment was validated and commented. The second session focused on the different technologies for decarbonisation and circularity and developed a prioritisation of these technologies. In the third session, the development of green products was in the focus of discussion and the fourth session discussed which uncertainties exist and which of those can be met and addressed at the European level.

The specific content of the breakout sessions is discussed in more detail in the annex. The breakout sessions were facilitated by TRANSIENCE and AMIGDALA partners. While the sessions were led by different teams, all contributed valuable insights into stakeholder needs at the European level and helped to identify critical knowledge gaps.

3 Common Challenges, Drivers and Barriers of Industry Transformation

During the regional workshops, challenges, barriers and drivers were structured by the topics decarbonisation, circularity and other sustainability aspects. Tables 3-5 synthesise the inputs from the four regions. Several aspects came up in more than one region, such that some challenges, drivers and barriers are shared between the regions and can be generalised, while others are region-specific. After a general description of the challenges, drivers and barriers, seven key thematic areas are presented that have been identified as common challenges affecting all regions, albeit to varying degrees.

From a technological standpoint, all regions identified infrastructure deficits as a key decarbonisation barrier, while acknowledging the availability of net-zero technologies as a driver (see Table 3). Some workshops delved into specific technological challenges, such as decarbonising non-electrifiable industrial thermal demand, while others addressed broader infrastructure needs for hydrogen, carbon dioxide, and electricity.

Economically, high investment costs and the economic viability of green investments and products were recurring concerns. Perspectives on pricing varied: while the Rotterdam and Basque country case studies highlighted the fear of high CO2 prices as a transformation driver, Rhine-Ruhr participants emphasised energy price stability as a major challenge, coupled with a comparative disadvantage due to low renewable energy potential. Here the regional assessment exhibited slight differences. For instance, both the Rotterdam and Basque Country case studies identified ETS pricing and long-term business case expectations for green products as drivers, whereas the Rhine-Ruhr Area focused more on the current lack of a business case as a barrier. This reflects a divergence in short- and long-term perspectives. The need for additional support for SMEs and recognition of their unique characteristics emerged as a common theme across regions.

On a political and institutional level, ambitious decarbonisation targets and corresponding regulations were recognised as major drivers. However, (geo-)political instability was identified as a significant institutional barrier, undermining regulatory credibility and increasing investment reluctance. The prevailing uncertainty was seen as too high for investment decisions in new, green production capacities. The expectation was formulated that the government should create stable and predictable framework conditions through credible regulation, be it about prices of energy, carbon, and hydrogen, infrastructure or funding mechanisms.

One international competitive advantage of all regions was their existing capacities, including public sector capacity (political and administrative), as well as innovation, adaptation, and human capital capacities. These assets facilitate innovative solutions and a smooth transformation. Another major competitive advantage is the high level of clustering and interdependence among regional firms, coupled with a collaborative culture and existing governance structures. However, these interdependencies can also complicate decision-making processes and hinder individual transformation efforts, thereby acting as a barrier.

Circular economy measures present a more complex picture, with more diverse and less straightforward technological options (see Table 4). Eco-design was frequently highlighted in the workshops as a crucial starting point for transitioning industry toward circularity. This directly connects to the current shortage of high-quality recycled materials and underscores the need to shift focus from recycling to higher R-strategies. In general, circular economy needs more structural and deep transformation than decarbonisation, as is cannot be reduced to production processes. This can be also seen in the fact that participants emphasised existing knowledge gaps and limited understanding in the realm of circular economy.

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Again, the proximity of actors and the existence of local supply chains were identified as potential drivers for a transformation towards circularity, enabling the interlinking of industrial flows and reducing the dependence on critical raw materials. In the Basque region and the port of Rotterdam, low land availability was discussed as a barrier to build circularity-related infrastructures/facilities.

Concerning other sustainability dimensions, mostly further environmental and social impacts were discussed and the need for a holistic assessment was emphasised (see Table 5). Existing experience, enhanced reporting demands (e.g. the CSRD) and increasing pressure through the finance sector were identified as driver for sustainable developments. On the other hand, the limited liability of the industry and the resistance to change were discussed as barriers.

Table 3. Overview of key decarbonisation challenges, drivers and barriers identified in the four case studies.

	Challenges	Drivers	Barriers
Technological	Non-electrifiable thermal Demand of Industry (B) Potential for utilisation of waste heat (B) Development of brownfield sites (S) Electrification (S) Decentralised power grid (S)	Availability of the main decarbonisation technologies (B) Hydrogen can compensate for RES intermittency (Ro) Potential to use legacy infrastructure (S)	Lack of infrastructure (B,S,RR): power grid expansion/ congestion (Ro, B); Infrastructure for CO2 capture Risk of slow or failed technological learning (electrolysis, pyrolysis, CCS etc.) (Ro, RR) Uncertainty regarding the role of specific technologies (e.g. H2, alternative fuels, CCS/U, etc…) (B)
Economic	Impact of decarbonisation on SMEs (B, Ro) (downstream in the value chain) Access to finance for decarbonisation (SMEs) (B) Need for stable prizes (RR)	Preparing for a future business case (Ro) Concerns of CO2 price skyrocketing in the future ('ETS fear') (Ro, B)	Low renewable energy potential (B, RR, S) No business case for green products (RR) High investment costs for new facilities and infrastructure (Ro)
Political & Institutional	Dependence on changes at structural level (B) Enabling stable policy frameworks for the green transition (B, RR) Credibility of regulation (RR)	Decarbonisation targets set at all administrative levels (Ro, B) Internalisation of emissions through taxation (B)	High geopolitical uncertainty, delaying investment from companies (RR, B) Fear of worsening business environment (Ro) Limited funding capacity (both private and public) (RR) Lack of public acceptance of new technologies (e.g. CCS) (Ro)
Capacity & Awareness	Need for effective bureaucratic structures (RR) Need for skilled workers (RR, S)	Public Sector Capacity (RR, B) Industrial and innovation capacity (B, Ro) Industries are evaluating their adaptation capacity (B) Increased societal awareness (S) Education (S) Long-term saving from green investments (S)	Lack of skilled workers (RR) Reluctance to reskilling (S) Higher costs of green products can deter consumers (S)

Networks	Ecosystem level perspective, to consider the impact of decarbonisation of industry along with other activities (e.g., mobility) and a territorial perspective. (B) Need to assess impacts on an aggregate basis (B)	Collaborative culture among institutions, industrial actors and other stakeholders at regional level (B) Governance structure in place to facilitate collaboration (Ro) Existence of relevant value chains and industrial sectors in the region (B) Interdependences as strong regional competitive advantage (RR)	Exposure to external markets and geopolitical issues as competitiveness risk (B, RR) High dependency on critical materials (B, RR) Interdependence as barrier for individual transformation efforts (RR) Divergent interests (S) Complex decision-making structures (S)
Location		Offshore wind potential (Ro) Availability of CO2 storage (e.g. North Sea bed (Ro)	Limited CO2 storage capacity nearby (Ro)
Regions: Basque Country (B); Rhine-Ruhr Area (RR), Rotterdam (Ro), Silesia (S)			

Table 4. Overview of key circular economy challenges, drivers and barriers identified in the four case studies.

	Challenges	Drivers	Barriers
Technological	Need for Innovation to transform waste into a good (B); Difficulty in valorising material flows (B); Waste segregation (S); Battery recycling (S)	Eco-design of products (B); Research on new materials and "R-technologies" (B)	Low availability of high-quality recycled materials (RR)
Economic	Creation of secondary markets in key materials (B)	Proximity of actors, local supply chains (S); Business models based on circularity (B)	Low demand for recycled materials (RR)
Political & Institutional	Need for institutional capacity in managing industrial synergies (B); Critical materials are not in Europe, geopolitical issues and material dependency (B, RR); Regulatory transformation (S)	Minimum recycling quotas (RR, S); Securitisation of materials supply chains through strategic and coordinated actions at EU level (B)	Low land availability for circularity-related infrastructure (B, Ro); High land prices (S); Lack of social acceptance of circularity infrastructures (NIMBY attitudes) (B); The overall circularity of the industry is still very low (B); Regulation can increase bureaucratic burden (S)
Capacity & Awareness	More knowledge needed on strategies to extend life cycles and use renewable and non-toxic materials. (B); Limited understanding of the circular economy, often conflated solely with recycling (RR). Need to raise awareness and knowledge of circularity among citizens (B)	Industry is familiar with eco-design of products and services (B); Lighthouse circularity projects (B); Industry's demand for profiles specialised in eco-design and circularity (B)	Circularity is not a real concern for industry, unless it is forced upon it (B); No use of higher R strategies (RR)
Networks		High industrial density is positive for linking industrial flows (B, S)	Changes in material flows, affecting the synergies in the clusters (RR)
Regions: Basque Country (B); Rhine-Ruhr Area (RR), Rotterdam (Ro), Silesia (S)			

Table 5. Overview of key sustainability challenges, drivers and barriers identified in the four case studies.

	Challenges	Drivers	Barriers
Technological	Need for holistic assessment considering both environmental and social impacts (B) Nitrogen emissions, air quality, environmental protection (Ro)		
Economic		Increasing pressure through interest in green finance (S) Local consumption driving industrial performance (B) Subsidies and investment support are critical for a successful transition policy (B)	Limited liability for the environmental impacts of industry. The scope of the vision is only inward-looking (B)
Political & Institutional	Ensuring a just transition, particularly involving SMEs in the transition and not "leaving them behind" (B) Managing the potential intermediate negative impacts of the transition on employment and the economy (B, RR)	Increasing transparency through new reporting (CSRD) (S) Public-Private cooperation (B)	Resistance to change of society, businesses and public administration (B)
Capacity & Awareness	Increasing sustainability requirements for the manufacturing industry. The requirements focus especially on environmental aspects, leaving economic and social sustainability on a second level. (B)	Good availability and commitment from industry (B) Experience of the environmental sector (environmental consultancy companies, service providers, etc.) (B)	
Regions: Basque Country (B); Rhine-Ruhr Area (RR), Rotterdam (Ro), Silesia (S)			

3.1 Political Uncertainty

The COVID pandemic, the Russian Invasion of Ukraine and the intermittent disturbances of global supply chains that resulted from these events have led to a much-increased perception of risks and uncertainties at global scale, while previously many people including industry decision makers were operating under the assumption of stability. As one participant from the Rhine Ruhr case study put it: "We were operating under the impression of a fundamentally stable system that is being thrown out of balance by external changes. While climate protection was still a comparatively controllable task, this is now being jeopardised by further external shocks. Now the impression seems to dominate that the system is fundamentally unstable, uncertain and volatile and is barely held together."

The uncertainty covers several dimensions: for some industries, particularly the chemical industry, **technological uncertainty** still looms large, **geopolitical uncertainty** has become a recent concern, **uncertainty about the availability and price of key resources** – renewable electricity, hydrogen, and critical raw materials – is a major concern, and finally the surge of right-wing populism and in many cases anti-democratic tendencies across Europe have created another layer of **political uncertainty**.

These uncertainties are particularly problematic because industrial regions are facing an investment bottleneck: many industrial production facilities will require reinvestment in the near future. At the same time, (public) infrastructure, most notably grids for electricity, hydrogen and CO2, require massive investments. But public coffers are under stress and the recent hike in interest rates create significant political pressures.

This political uncertainty can be displayed in a causal loop diagram. This has been developed on the basis of the Rhine-Ruhr case study but is applicable with minor adjustments to other cases (see figure below).

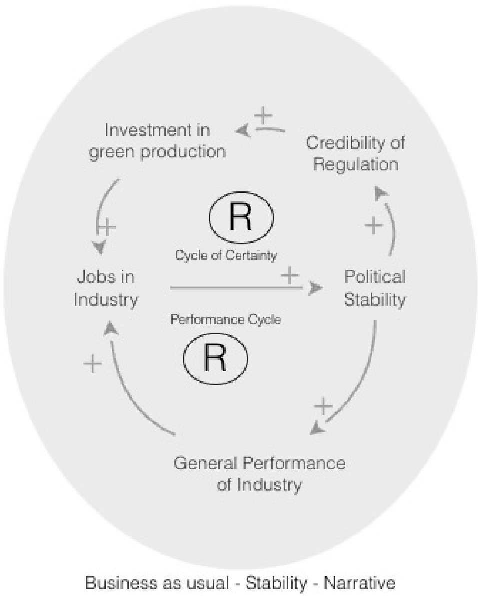

Figure 4. Step 1 of the Political Uncertainty trap causal loop diagram.

Starting from a perception of a relatively stable economic and industrial system, we depict the core system with two connected reinforcing feedback loops. The upper "certainty cycle" illustrates how political stability can create an environment where regulation is perceived as credible, fostering clear conditions for investment. Increased investment and job creation can, in turn, reinforce political stability. The lower "performance cycle" demonstrates how political stability can benefit overall industry performance, leading to more jobs and reinforcing political stability.

While these circles can work as mutually reinforcing virtuous cycles of stability, certainty and high performance, they can easily become vicious cycles of uncertainty, where political instability undermines the credibility of regulation and generally uncertainty about framework conditions increases, leading to a reluctance in investment. This means that less (green) jobs are created and general satisfaction decreases. Thus, political stability decreases further.

Such a situation was described by several participants in the workshop. It was discussed that the uncertainty in general is too high to take investment decisions in new, green production capacities. The expectation was formulated that the government should create stable and predictable framework conditions through credible regulation, be it about prices of energy and hydrogen, infrastructure or funding mechanisms.

The uncertainty that is described by the participants is triggered by external factors, such as climate change, or geopolitical factors (Figure 5). Political stability can facilitate the development of climate regulation by fostering an increased acceptance of necessary transformations. However, climate regulation often introduces additional bureaucratic procedures. While bureaucratic structures and capacity can enhance stability and credibility, they can also hinder investment through lengthy permitting processes and excessive paperwork. Consequently, climate regulation may lead to a decrease in investment due to increased bureaucratic burdens. Moreover, climate regulation, particularly instruments designed to internalise emission costs, such as the EU ETS, can increase production costs for emitting firms, potentially weakening their competitiveness and hindering overall industry performance. While climate regulation is essential, and price-based instruments are often the most economically efficient, they can also have adverse effects. The costs of these instruments are concentrated, while their benefits may be dispersed over time (Juhasz, 2024).

Not only climate change but also the change in geopolitical conditions has an influence on the industrial system (Figure 5). The increased geopolitical rivalry negatively impacts both the political stability and the competitiveness und general performance of the domestic industry in Germany and Europe. On the other hand, it comes with an increased focus and interest in national production, that can lead to more subsidies and thus more investment in green technologies.

Finally, the investment bottleneck discussed above can be represented in the form of budget trade-offs constraining industrial policy (Figure 6). As the budget is fixed, especially due to the debt ceiling enshrined in German federal constitutional law but also due to the fiscal rules of the European Union, public funding capacities are limited and policies in one field are at the expense of expenditures in other areas. A positive general performance of the industry can alleviate the pressure on the budget to some extent through higher tax revenues, but the general trade-off persists, as long as the debt ceiling is in place.

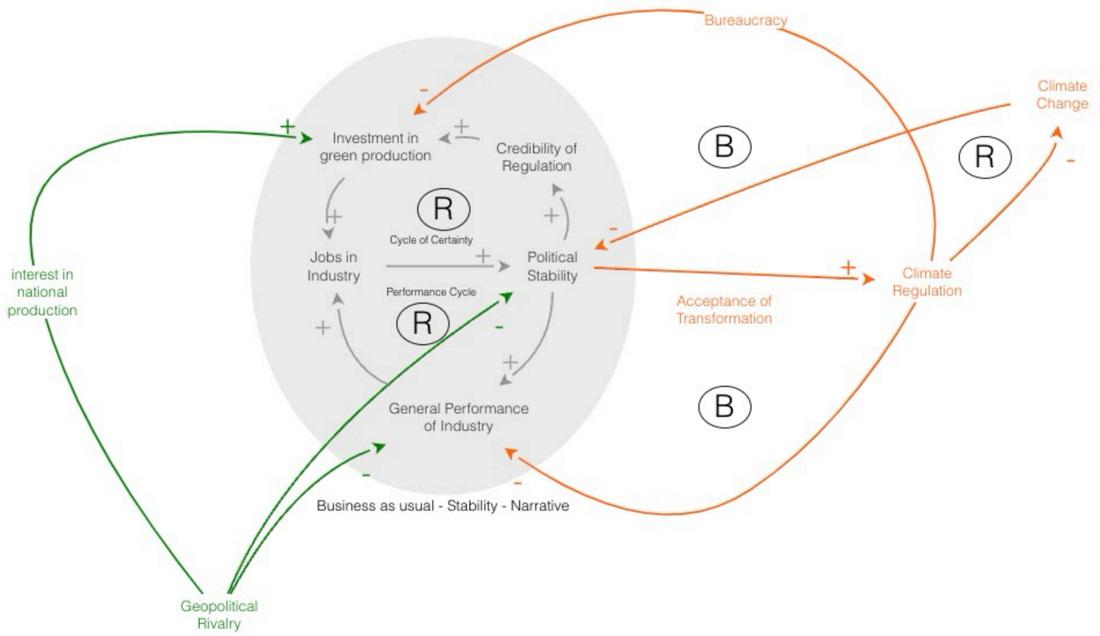

Figure 5. Step 2 of the Political Uncertainty trap causal loop diagram.

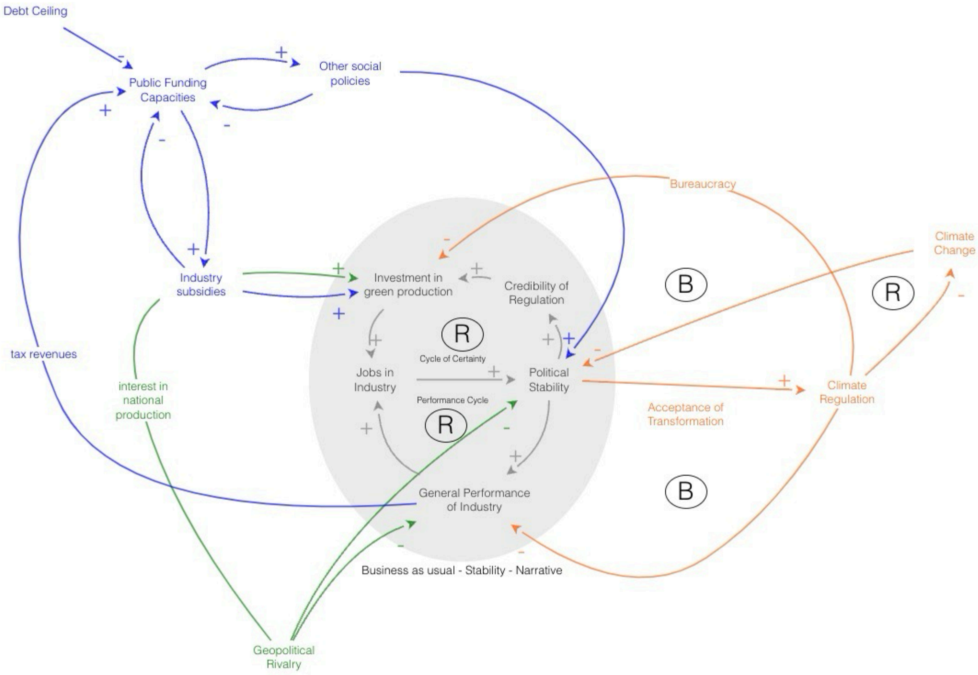

Figure 6. Step 3 of the Political Uncertainty trap causal loop diagram.

3.2 Economic Viability of Green Materials

A specific and particularly plaguing aspect of the general issue regarding uncertainty is the issue of uncertain economic viability of green materials. While it seems almost certain that the viability of conventional emission-intensive materials will wane eventually, at least within the European Union, there is currently no solid business case for green materials, either. To date, no market exists for green materials and while some consumers have expressed general interest in purchasing green materials – for example the automotive industry has expressed interest in procuring green steel – it remains unclear how large the price premium would be that the potential buyers would be ready to pay.

This issue has several dimensions: first, green materials do not significantly differ from conventional ones with respect to their functional properties, e.g. the quality of the steel is the same. What is different is the production process. But currently there is no way of differentiating green from grey steel. Numerous initiatives are currently preparing certification and labelling schemes for green materials to change this situation, but none of these initiatives has already certified corresponding products and certainly no universally accepted standard has been adopted. Second, genuinely green materials are currently not yet available in bulk volumes. For green steel, only one demonstrator plant is currently operating and producing steel from green hydrogen. Several others are under construction, and even more are in various stages of planning. Finally, it remains unclear at which costs manufacturers will be able to produce green materials. Uncertainty about prices for green electricity and even more importantly green hydrogen is still too large to make reliable cost projections. Interestingly, participants Silesia and the Basque Country expressed optimistic views regarding hydrogen whereas in the Rhine-Ruhr region stakeholders noted a phase of hydrogen "hangover" after a previous hype.

As a result, investments in green production facilities are extremely hard to finance. It is hard to convince a bank to provide a major loan for a product that does not have a market (yet). While some participants remain

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optimistic about long-term profitability, others voice reservations, emphasising the need for robust government support and clear market signals to incentivise investments in unproven technologies.

3.3 New Industrial Geopolitics

As stated already above, changing industrial geopolitics are of major concern for industrial stakeholders. This is particularly pronounced in the Rhine Ruhr area, Germany, with its very export-oriented economy and the Port of Rotterdam as a major hub in a globalised economy. But similar concerns also prevailed in Silesia and the Basque Country. Competition from China is seen as a major threat. During the Rhine-Ruhr workshop it was mentioned that, in the past, German products were seen as superior products which could command higher prices. Now for the first time Chinese competitors seem to be not only cheaper but also offer superior products and it is Germany that needs to catch up technologically.

Of course, global competition is also driven by policy. China has been providing substantial subsidies to its domestic industries and now the United States have also started to hand out substantial subsidies under its Inflation Reduction Act. Industrial stakeholders were sceptical whether the EU and its Member States will be able to match these subsidies and provide similar framework conditions for European industry. Specifically, stakeholders were critical of the EU's Carbon Border Adjustment Mechanism (CBAM). They were sceptical whether it would be effective in protecting domestic markets, fearing inter alia loopholes in the implementation of auditing and monitoring. Moreover, the current policy design does not foresee any compensations for companies exporting outside of the EU, placing those companies at a particular disadvantage in global competition.

Besides these economic concerns, industrial stakeholders also harboured security-related concerns. In case of escalation of geopolitical conflicts, will critical raw materials and key commodities remain available? Here participants also expressed some hope that establishing a circular economy in Europe could help to mitigate dependencies both in relation to resources prices as well as related to scarce materials like critical raw materials. However, whether it would be possible to harvest Europe's rich secondary resources and how that would affect economic resilience remains an open question.

Finally, industrial stakeholders agreed that their own competitiveness is linked to the close integration across industries in their respective clusters. In many cases, one company's waste is another company's feedstock, creating a form of industrial symbiosis. Maintaining these synergies was a key concern for many stakeholders. However, it is unclear how strong the locational advantages arising from clustering and geographical co-location are vis-à-vis locational advantages from abundant cheap (renewable) energy. Moreover, there is major concern that changes in the symbiotic system – whether due to company closures due to lack of competitiveness or due to investments into new transformative technologies – may have cascading effects on other companies in the industrial eco-system (cf. Janipour et al., 2022).

3.4 Complexity Is Holding Back Circularity

While all regions generally support the development of a circular economy, it is also clear that this aspect has received comparably less attention. In part that is because the solutions are much more complex. Achieving a circular economy requires the simultaneous implementation of several "r-strategies": refuse (avoid unnecessary consumption), reduce (minimising consumption e.g. through resource-efficient product design), reuse (extended product life through more frequented uses and repurposing, incl. sharing), repair (designing products so that they can be repaired easily and cost-effectively), refurbish (enhancing appearance or functionality of a product), remanufacture (restoring products to their original condition or better through a complete overhaul), recycle (recovering valuable materials from waste), and recover (extracting energy from waste materials). Yet, discussions on circularity, especially when in the context of climate change, frequently focus quickly on recycling and recovery. Higher level "r-strategies" such as remanufacturing and extending the lifespan of products (repair and reuse) are hopeful options, but the potential of these approaches to reduce the need for primary production and contribute to decarbonisation efforts remains largely unknown. Moreover, there is need for regulations and incentives to encourage these practices.

But even regarding recycling complexity prevails. While local actors may be familiar with material flows within their respective industrial cluster, it is unclear at which level loops should be closed. For some aspects closing material loops locally is an obvious choice, but for products and materials that are traded globally closing the loop at the national, European or even global level might be more appropriate.

These challenges about circular economy particularly affect the chemical industry as chemical recycling is one of the potential alternatives to replace feedstocks from virgin fossil fuels. While this might appear like an ideal option to curb emissions of the sector, it comes with practical challenges. For example, in the Port of Rotterdam case study it was found that even closing material loops for plastic at a national level would not suffice to supply enough carbon feedstocks to replace current levels of fossil fuel feedstocks. Moreover, it would require significant new infrastructure to sort, store and process waste before it can be used as a feedstock. All this infrastructure requires space, and space is limited in the port (see section 3.6 below).

3.5 Technological Infrastructure

Investments in technological infrastructure are key for accelerating the transition towards decarbonisation in all the case study regions. Electricity grid enlargement to meet the electrification needs of industry is an important precondition for decarbonisation in the Basque Country and Rotterdam Port, whereas the emerging infrastructure for green hydrogen is essential to drive the transition forward in Germany to ensure well-functioning market and more predictable pricing of green hydrogen. In Rotterdam Port, the on-going decarbonisation projects, including infrastructure for hydrogen, Carbon Capture and Storage (CCS) and new facilities for biorefineries are paving the way towards decarbonisation. However, further infrastructure investments are needed to adapt the existing fossil-fuel based refinery infrastructure to meet the needs for handing renewable feedstocks. In the Basque Country, the CCS and hydrogen infrastructure are seen also as potential drivers for the transition, with some reservations due to the current uncertainty regarding future perspectives of these technologies though. In Silesia region, the transformation of the energy system, historically based on coal, is requiring significant infrastructure funding.

The transformation to green production processes in the **Rhine-Ruhr area** requires massive investments in new plants and new infrastructure, since many assets are approaching the end of their lifetime and require updating and upgrading. However, the implementation of this infrastructure is hindered by investment backlog caused by a bad economic situation and geopolitical competition. For the steel industry, green hydrogen will be the primary fuel and reducing agent. Although the hydrogen infrastructure is picking up pace in the region, the investment in electrolysers is lower than anticipated and less progress is being made in the technological learning curve. In terms of a future perspective the development of infrastructure for green molecules and energy is a key enabler for a more sustainable industry in the Rhine-Ruhr area.

The industry in **Basque Country** is facing limitations given by the energy infrastructure. The capacity limitations of power grid infrastructure are limiting further electrification of the energy system, which is an important factor to decrease the fossil fuel dependency in the region. In addition, the low renewable energy potential available locally in the Basque Country hinders the decarbonisation capacity of the industry within the region. The same limitations concerning circularity are seen in the Basque region where a better infrastructure is needed, particularly for recycling purposes. This need comes up against the lack of land for setting up these infrastructures and of social acceptance, including "*Not In My Back Yard*" attitudes. Technological advances and improvements are thus essential for achieving a decarbonised and circular industry in the region. Long-term infrastructure planning and the expansion of the power grid are significant challenges to be addressed to enable industrial transformation.

The **Port of Rotterdam** has already on-going infrastructure projects targeting decarbonisation, including development of a hydrogen infrastructure and a Carbon Capture and Storage (CCS) project, which aims to store 2.5 million tons of CO_2 annually under the North Sea. Although the CCS can deliver short-term emissions reductions, its long-term sustainability is questionable and its development may hinder the deployment of more sustainable technologies, such as renewables. Although the Port of Rotterdam is already facing emergence of investments on biorefineries, the majority (90%) of the total refinery capacity is still based on fossil fuels. To achieve the decarbonisation, more infrastructure suitable for handling alternative circular feedstocks is needed. The current infrastructure, including storage tanks and pipelines designed for crude oil, may not be suitable for handling alternative, more sustainable feedstocks such as solid or semi-solid feedstocks like biomass or processed waste materials. Adapting infrastructure to accommodate these new feedstocks would require significant investment. In addition, the decarbonisation of the Port, and particularly of chemical producers, requires the uptake of the electric infrastructure to support the electrification of specific industrial processes. Similarly to the Basque Country case, investments are required for the expansion of the existing grid capacity.

In **Silesia** region, the technological infrastructure is an especially important driver for transforming the energy system historically based on coal. The heavy industry is envisaged to use renewable energy sources in future. The region envisages the development of biomethane and biogas plants, utilising organic waste available locally for generation of heat and power. The decarbonisation of the regional fuel mix will therefore require large investments. The potential development of the recycling industry (e.g. launch of the Bedzin battery recycling plant) will contribute to the fostering of secondary markets and circularity improvement of the region, reducing waste and allowing the recovery of valuable materials, but requiring of additional investments for the development and deployment of recycling technologies and infrastructures. The existing industrial infrastructure in the region (e.g. access to transport and energy) is seen also as a facilitator for the transition, lowering the investment costs for new emerging businesses.

3.6 Space Constraints in Existing Industrial Landscapes

Availability of land is a challenge for Basque Country and Port of Rotterdam. Highly packed industrial zones and spatial constraints preventing further expansion of industrial areas are hindering factors, especially for large infrastructure investments needed for advancing decarbonisation and circularity. Conversely, dense industrial areas and geographical proximity of industrial companies from different sectors can be considered as an asset for reinforcing industrial symbiosis and circularity due to use of secondary materials and leveraging from complementary business models joining the different actors of the value chain. In Silesia region, the availability of brownfield sites, left behind by pacing out industries, are bringing an opportunity for reutilisation for greener investments.

The shortage of land for industrial infrastructures in the **Basque Country** is seen as a significant challenge hindering the competitiveness and the transition towards a greener industry. The lack of new industrial land affects both the expansion of existing infrastructures and setting up new ones. This is especially crucial for circularity-related infrastructure, where difficulties arise for new industrial projects to find specific locations. The consequence is the loss of competitiveness compared to other regions with better availability of land for industrial infrastructures.

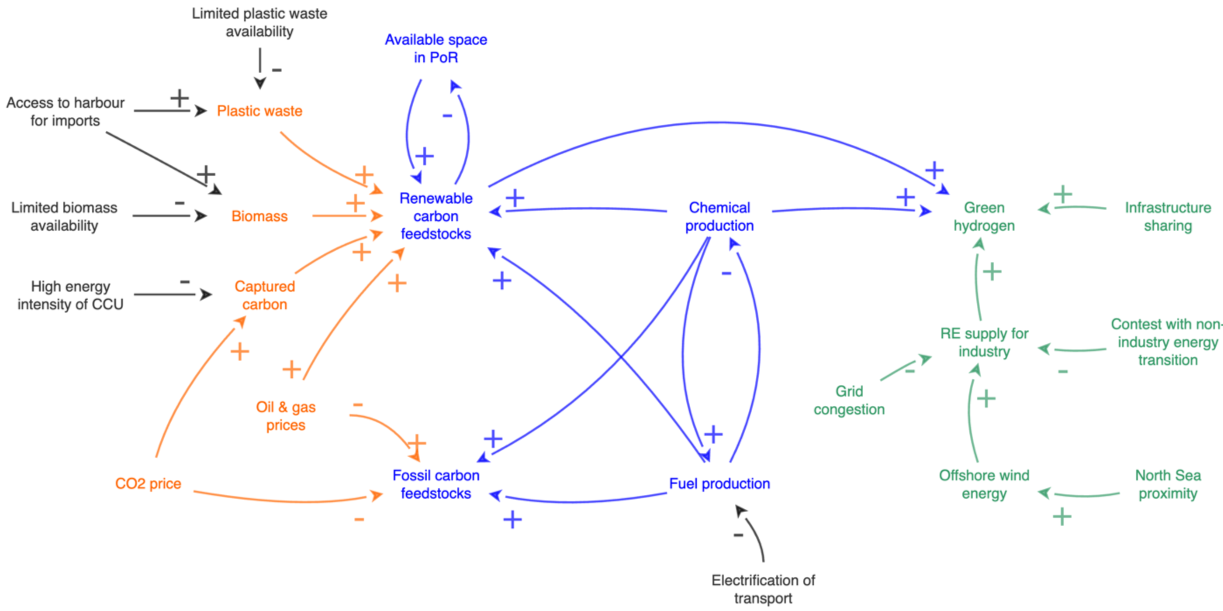

Figure 7. The choice of future feedstocks is constrained by space availability and North Sea proximity in the Port of Rotterdam.

One of the challenges related to green transition of **Port of Rotterdam** is related to spatial constraints (see Figure 7. The area of the Port is very densely built and there is limited space for constructing the new infrastructure, e.g., for biorefineries, needed for the transition. The land use of the Port is a subject of policy debate on future spatial planning, some favouring expanding the Port area, others concerned about the availability of space for logistics and feedstock storage. Some forms of feedstock, such as biomass, have a lower energy density than crude oil necessitating larger storage capacities, which further challenges the Port's spatial constraints.

The **Silesia** region is characterised by a high number of brownfield sites offering an opportunity for reutilising the remaining infrastructure from the industry previously operating at the site. However, the reuse and rehabilitation of the brownfield sites may require high level of investment and some of the areas are difficult to access. Degradation and pollution of land in industrial areas poses an additional challenge, requiring environmental technology solutions for cleaning the land. Since the land prices of industrialised areas of Silesia are high, this would raise the cost of investments and business operations significantly.

3.7 Ensuring a Just and Real Transition

The human dimension and social aspects of the transition were highlighted in three of the four case studies. Indeed, transformation of the European industry may entail drawbacks (e.g. job losses, shutdowns, etc.) generating social unrest and opposition. It is therefore crucial to address the industrial transition under a social perspective, too.

First, social acceptance regarding specific decarbonisation and circularity solutions should be considered and evaluated. On this concern, the potential adoption of more sustainable consumption patterns that may affect the consumption level of industrial products and other goods and services (and therefore impact on the productive fabric) should be assessed.

In addition, the use of other indicators to drive and parametrise socioeconomic development and assess its performance was suggested in the Basque Country workshop. Externalities (e.g. health concerns) should be also taken into account when quantifying transition pathways.

Second, it is vital to ensure a just transition that will consider both the companies and workers. Rhine-Ruhr and most specifically Silesia case studies highlighted the need of upskilling and reskilling workers from non-competitive or pollutant industries that should be transformed (e.g. coal mining in Silesia). Public programmes, frameworks, and funding should be established to reconvert and transfer those workers to more sustainable sectors.

Also on this concern, taxation should lead to compensate potential downsides of the industrial transformation. The impact of the transition on SMEs was also mentioned in both Rhine-Ruhr and Basque Country regional workshops. Since SMEs may have a tougher adaptation than large companies, they should be supported by funding programmes and public assistance.

Finally, a reflexion is to be made on how the industries at the core of the current unsustainable energy system will be transformed and how this transformation will be managed. Indeed, energy transformation and supply sectors such as oil refining (cf. Rotterdam Port) or coal mining (cf. Silesia region) might be phased out or heavily transformed if climate goals want to be achieved. If our current habits must change (i.e. how we heat our homes, how our journeys are made, how much we consume, how industrial processes are fuelled, or how goods are transported), the current energy model will be impacted, and more concretely the sectors at its root – the energy conversion sector and energy-intensive basic raw materials sectors. This transformation however may be an opportunity to rethink and redistribute the profits that industry and energy sectors currently generate.

4 Conclusions and Main Stakeholder Needs

The four regional case studies exhibit surprising levels of similarity. Despite the significant differences with respect to the socio-economic circumstances, industrial ecosystems and transformation progress, stakeholders are experiencing similar challenges, drivers and barriers. We have synthesised the most salient themes into seven thematic areas: challenges related to political uncertainty, the economic viability of green materials, new industrial geopolitics, complexity as a barrier holding back advances towards a circular economy, needs for new and adapted technical infrastructure, challenges related to limited space and the need to work with existing brown-field industrial sites, as well as the socioeconomic aspect of the transition.

Not all of these themes are directly amenable to scenario-based modelling analyses. Nevertheless, we will attempt to extract research questions from these challenges which may, in turn, be converted into design requirements for the MIC3 modelling ecosystem. The following research questions are distilled from the key thematic areas outlined in section 3 above:

1. **How resilient are decarbonisation pathways and strategies against drastic price shocks or supply chain disruptions**? Recent history has led to a significantly increased risk/uncertainty perception of industrial stakeholders. They would appreciate more extreme security-informed scenarios reflecting dramatically different prices and/or restricted availability of some resources.
2. **What are the costs of economic resilience and how can we measure it?** From an industrial policy perspective, we might need to subsidise some strategic but potentially uncompetitive industries (e.g. critical raw materials, microchips). The question is which sectors and how much should they be supported? This question is closely related to the need for more extreme security-related scenarios which provide clues as to which sectors are particularly relevant for economic resilience and which ones might be more easily substituted.
3. **Which effect can circular economy strategies have in enhancing resilience and competitiveness of EU industries?** While Europe may have limited remaining natural resources, it is rich in secondary resources. The questions how these can be leveraged to mitigate price and availability concerns related to raw materials.
4. **Which public investments are key and need to be prioritised? And can we design decarbonisation pathways that minimise (public) investments?** Political uncertainty is increasingly perceived as a main barrier for investment decisions. It is partly fuelled by the perception that governments are unable to leverage the required (public) investments and there is increasing competition between different policy areas over scarce public resources. This raises the question of prioritisation.
5. **What are potential socio-economic impacts (incl. distributive and health impacts) of different decarbonisation and circularity solutions on social acceptance and consumption patterns?** Stakeholders acknowledge the importance of the social dimension of transitions. If not addressed, there is a risk that backlash and resistance will further enhance political uncertainty creating a reinforcing feedback loop with the investment bottleneck highlighted above.
6. **How fast are markets for green raw materials going to develop under a variety of policy measures to support green lead markets?** Current models typically only provide for aggregated demand for specific materials that lacks granularity in terms of the different qualities required, the location of the demand or the production method used. In order to provide a clearer picture models

would need to differentiate markets for green vs. conventional energy-intensive commodities.

7. **How potent are locational advantages of clustering vis-à-vis locational disadvantages related to limited availability and comparatively high cost of energy supply (RE and hydrogen)?** Industrial stakeholders perceive cluster effects and industrial symbiosis as key for their current and future competitiveness. Perhaps the question is how these locational advantages of clustering can be represented in models, because if they are not, we are missing an important part of the competitiveness picture and run the risk of creating self-fulfilling prophecies of waning competitiveness.

8. **What is the impact of different decarbonisation infrastructure investment strategies on emissions reduction, economic competitiveness, and energy security in regions heavily reliant on fossil fuels?** As the insights presented above highlight, infrastructure investments are imminent and key to unlock full decarbonisation. To take investment decisions, the effectiveness and trade-offs of these different investment strategies needs to be explored across key sustainability dimensions: emissions reduction, economic competitiveness, and energy security.

9. **What are trade-offs between spatial limitations, which can hinder large-scale infrastructure development, and the potential benefits of geographical proximity for fostering industrial symbiosis and circularity?** So far, space constraints are hardly taken into account in scenario modelling but may significantly limit the available options to implement specific decarbonisation strategies. This is particularly relevant for the chemical industry where it is clear that from a global or European perspective biobased feedstocks, carbon-rich waste and captured carbon from other processes will all play a role as alternative feedstocks to substitute virgin fossil fuels. But at the site level, tough decisions will have to be made as to which strategy is the right one to convert this specific site.

10. **What are the interdependencies and trade-offs between green feedstocks for chemicals (circular/renewable carbon or biogenic carbon) vis-à-vis other energy uses?** Currently, the policy landscape for industrial biomass use (especially on EU-level) is very much focused on the production of sustainable fuels inter alia for aviation and shipping and almost completely absent for sustainable chemical production. Similarly, the uptake of renewable carbon feedstocks also requires an 'industrial energy transition', which will compete for resources and policy attention with the ongoing non-industrial energy transition.

Addressing these research questions may help regional stakeholders to navigate what appears to be an overwhelming level of uncertainty. It can help them to build a more confident understanding of future developments and the framework conditions under which they might unfold. On the basis of this better understanding, the necessary investment decisions may more easily be taken to advance the transformation of European industries.

Subsequent discussions within the TRANSIENCE consortium will explore whether and to what extend the MIC3 modelling eco system will be able to contribute meaningfully to these questions.

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Annex A: North Rhine-Westphalia Regional Case Study

Miriam Ruß & Lukas Hermwille

A.1 Introduction

There is a growing need for integrated, economy-wide approaches to address climate action, resource efficiency, and circularity. However, existing modelling capacities often struggle to capture the complex interplay between the circular economy and decarbonisation, particularly for energy-intensive industrial sectors. The TRANSIENCE project seeks to address this gap by developing MIC3, an open-source model ecosystem designed to assess the feasibility and impact of various industrial transformation pathways. The TRANSIENCE project draws on regional stakeholder processes to gather insights to inform the development of MIC3, ensuring that it adequately reflects the specific challenges and opportunities faced by regional stakeholders in their transition to a climate-neutral and circular economy. Engaging with regional stakeholders is crucial for identifying critical system dynamics, data needs, and potential policy interventions that can support the model's accuracy and relevance. This report presents a case study focusing on the Rhine-Ruhr Area in the state of North Rhine-Westphalia (NRW), Germany.

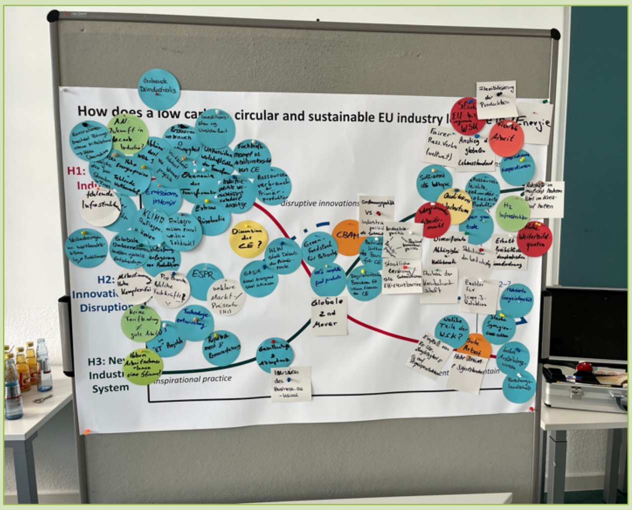
The Rhine-Ruhr area was selected due to its industrial significance, particularly in the steel and chemical sectors. These sectors face substantial challenges in transitioning towards decarbonisation and circularity, including maintaining global competitiveness amidst evolving energy landscapes and reducing reliance on fossil fuels as both energy sources and feedstocks.

The insights gained from this case study will directly feed into subsequent stages of the TRANSIENCE project, including the development of policy-relevant research questions and the validation of MIC3 through further case study analysis later in the project.

The remainder of this report will first provide background on the Rhine-Ruhr region, including a description of the area, justification for its selection as a case study, and identification of key industrial clusters. The report will then present the findings, drawing on insights from stakeholder workshops and analysis of existing modelling tools.

BOX 1: Case Study Method

The case study uses a mixed-methods approach, combining desk research, stakeholder workshops, and expert interviews. During the desk research phase, the author team surveyed and reviewed existing studies including relevant policy reviews to consolidate the case study background and to gain an overview of the extent to which modelling exercises are already being employed to support the transformation process in the region. In a second step, a stakeholder workshop was held in late August 2024 comprising participants from the regional state-owned energy



agency, from civil society (environmental NGO and trade unions), from infrastructure providers (gas natural gas, hydrogen and CO_2 prospectively), the German steelmakers' association, and academia. The workshop was facilitated using the Three Horizons facilitation method (Sharpe et al., 2016), a futures thinking technique that provides a framework for understanding and navigating complex change by considering three distinct but interconnected horizons. These horizons represent different perspectives on the future: the dominant present, the emerging future, and the transitional space between them, and the method explores how they interact and shape the dynamics of change. The insights generated in this exercise were synthesised by the author team and corroborated with workshop participants in follow-up communication.

A.2 Case Study Insights

A.2.1 Background: Description of the region and its industrial base

In this study, the Rhine-Ruhr region is defined as the area encompassing the administrative districts of Düsseldorf (NUTS2 Region DEA1) and Cologne (DEA2), located in western Germany near the borders of Belgium and the Netherlands. Düsseldorf and Cologne are among the most populous and densely populated districts in Germany. Together, approximately 9 million people live in this area, representing 11% of Germany's total population, despite comprising only 3.5% of the country's land area. This concentration of people reflects a high degree of urbanisation and economic activity. The GDP per capita in the Rhine-Ruhr region is around €44,000 per year, which is comparable to the national average for Germany. But the region constitutes a significant industrial hub within Germany. Specifically, it hosts 20% of Germany's chemical industry workforce and 23% of its metals industry employees, highlighting its disproportionate role in these sectors.[6]

[6] EUROSTAT Regional structural business statistics by NUTS 2 region and NACE Rev. 2 (2008-2020) https://doi.org/10.2908/SBS_R_NUTS06_R2

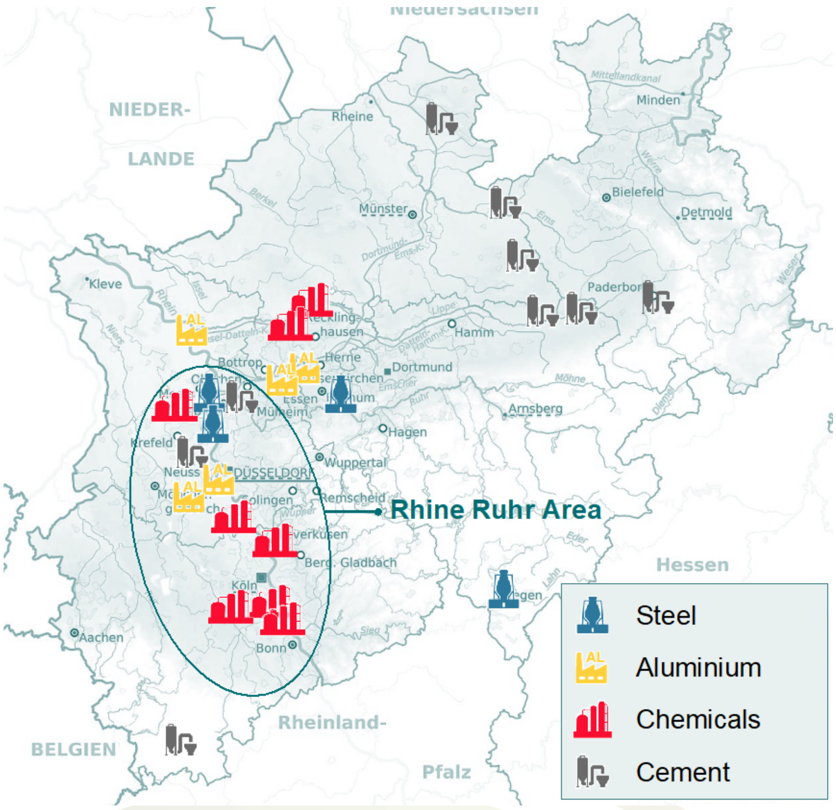


Figure 8. Location of key industrial sites of basic raw material industries in North Rhine-Westphalia. Source: Map by Kgsw, CC BY-SA 4.0, via Wikimedia Commons.

The Industry in the Rhine-Ruhr region consists of a historically grown network. The value chains developed in correspondence to the local occurrence of primary raw materials, such as coal, oil, and lime. Locally different availabilities shaped the development of regional clusters. For example, the existence of steel industry in the Ruhr area can be traced back to the abundant availability of iron ore and coal during the industrialisation. Indeed, one could even argue that the existence of the Ruhr Area as a major urban agglomeration is the result of the success of the coal and steel industries. However, hard coal production ceased in 2018 in the Ruhr Area. Since then, the steel industry is entirely based on imports of iron ore and coal, which arrive at the port of Duisburg, the biggest inland port of the world.

Still today, the city of Duisburg remains an example of the region's outstanding role for industry, especially the steel sector. The town hosts 8 out of 18 blast furnaces for primary steel production in Germany. This corresponds to an annual production capacity of 12.5 million tons primary steel, nearly 40% of Germanys total production capacity. While the primary steel production is done by big players such as ThyssenKrupp-Steel (TKS) and HKM (a subsidiary of TKS and Salzgitter AG) in Duisburg, this feeds into the steel and metal processing sector, consisting of various regionally located companies including many SMEs (Prognos AG, 2021). TKS have broken ground to build a new DRI (direct reduced iron) plant which will be able to produce 2.5 million tonnes of green primary iron based on hydrogen. The DRI will be fed into existing and new converters on site. The project has received a 2bn EUR grant under the Hydrogen IPCEI (important project of common European interest) programme.

The chemical industry is geographically clustered around the city of Cologne in the Rhineland region. It originated from the Rhenish lignite mining industry which provided abundant cheap energy. Initially, lignite was not only used as an energy input but also used as a feedstock in the chemical industry. Opened in 1937, the first plant established in Wesseling produced synthetic fuels from lignite. After the second world war and especially with the new refinery built at the Cologne-Godorf site in 1960, the production was converted to oil-based feedstocks.[7] Oil is mostly imported via pipelines from the port of Rotterdam and the sector is generally deeply anchored in the so called ARRRA[8] region (Scholz et al., 2024).

Today, the Cologne chemical cluster consists of 5 chemical parks: Cologne-Godorf, Wesseling, Hürth-Knapsack, Leverkusen and Dormagen with another site in Krefeld-Uerdingen nearby. In total, some 250 individual companies contribute ~22% of the German chemical industry annual turnover. At the core are two refineries in Wesseling and Godorf which produce 1.3 million tonnes of Naphtha annually. Together with additional imports of 6 million tons of Naphtha from the Antwerp and Rotterdam area, they feed six steam crackers with a combined annual production capacity of 2.5 million tonnes of Ethylene. Collectively, these chemical parks have an estimated primary energy demand of 100TWh per annum, which makes them by far the largest chemical cluster in Germany (Scholz et al., 2023). While still rooted in fossil feedstocks, also the chemical industry has started to move towards decarbonisation. For example, chemical giant LyondellBasell has broken ground at its Wesseling site to build its first industrial scale chemical recycling plant to turn post-consumer plastic waste into feedstock for production of new plastic materials. The new plant is expected to have an annual capacity of 50,000 tonnes per year.[9]

Both examples show how the value chains have changed significantly over the last decades such that the region is now deeply integrated into global value chains. The central location in Europe and the existing infrastructure played a vital role in the success of this historic transformation. This close integration and interconnection will also affect future transformations as the material flows of different industrial sectors are deeply interconnected as well. Local changes in one of the sectors have impacts on other sectors and firms that have to be taken into account (IN4climate.NRW, 2021). For example, the slag which is produced in the steel production, is later used as substitute for highly emission-intensive clinker in the cement industry.[10]

Table 6. Greenhouse gas emissions from key industrial sectors in North Rhine-Westphalia in 2021 (energy-related and process emissions). Source: Landesamt für Natur, Umwelt und Verbraucherschutz NRW, 2021.

Description	Total emissions [in million tonnes CO_2e]	Share
Total Emissions NRW	**217.264**	**100%**
Total Industry Emissions	58.370	26.9%
Iron & Steel	27.761	12.8%
Chemical Industry	14.900	6.9%

However, the importance of the industrial sector in the Rhine-Ruhr region is also reflected in the contribution to national emissions of this area. Due to data unavailability, it is not possible to provide data on greenhouse gas (GHG) emissions at the NUTS2 level. The following statistics therefore pertain to the entire state of NRW. However, given the concentration of the steel and chemical industry in the Cologne and Düsseldorf regions, the picture is still reasonably accurate. In 2021, emissions from the iron and steel and chemical industry amounted to 42.6 Mt CO_2e. This corresponds to 19.7% of the states total GHG emissions and 73%

[7] https://de.wikipedia.org/wiki/Rheinland_Raffinerie
[8] Antwerpen-Rotterdam-Rhein-Ruhr-Area
[9] https://www.lyondellbasell.com/en/news-events/corporate--financial-news/lyb-lays-foundation-for-1st-industrial-scale-advanced-recycling-plant-at-wesseling-germany-site/
[10] The cement industry is mostly located outside the Cologne (DEA2) and Düsseldorf (DEA1) districts but geographically close in the Eastern parts of the state of North Rhine-Westphalia (see Figure 1).

of industrial emissions.

Moreover, the material flows in NRW are still very much dominated by primary raw materials. Overall, the rate of recycled materials is estimated to amount to only.[11] 12.2% in 2019.However, the major share of recycled products belongs to the steel industry with 93% of scrap steel being recycled and a 47% share of recycled materials, and plastics with a recycling quota of 47% of end-of-life products and a share of 13.7% of recycled materials in production (IN4climate.NRW, 2021). Advancing towards a fully closed-loop circular economy remains a tremendous challenge for the region as the material flows of many branches of industry are closely interlinked and selective changes inevitably have an impact on several sectors and companies at the same time.

Consequently, the commitment to a climate-neutral industry in 2045 poses a significant challenge for the region. North Rhine-Westphalia has translated the overall German goal of climate-neutrality in 2045 into **state-specific goals of a 65% reduction of emissions in 2030 and 88% in 2040** (Gesetz Zur Neufassung Des Klimaschutzgesetzes Nordrhein-Westfalen, 2021; IN4climate.NRW, 2021). Such emission reductions can only be achieved, if the industry is structurally transformed. This implies investments in new productions sites and a transformation of material flows away from fossil fuels, both as energy source and feedstock. Therefore hydrogen, electrification, and clean electricity production are key parts, together with a strategy on how to make material flows more circular, including carbon flows. North Rhine Westphalia has addressed these issues in different strategies, decisions and roadmaps.

One central part of the transformation towards clean energy production is the phase-out of electricity generation with lignite. In 2022 the state government and the utility and mining company RWE operating in the Rhenish lignite mining area adopted an agreement to accelerate the phase-out of lignite production and lignite-fired power generation to 2030 (MWIKE, 2022). However, it is unlikely that NRW will be able to substitute all this power generation with domestic renewable electricity. As a densely populated state, the potential for renewable energy is limited in the state. Due to the large amount of renewable energy required for the production of green hydrogen and the stated limitations, it is estimated that only about 10% of the regional demand for green hydrogen can be met by regional production. The rest will have to be imported from other parts of Germany or internationally (Cerniauskas et al., 2021).

In terms of political processes, NRW has already advanced several strategies and initiatives. The general guidelines and transformation visions for the industry are given by the **industrial policy guidelines** (MWIKE, 2019) and the **sustainability strategy 2030** (MUNV, 2020). The **hydrogen roadmap NRW** (MWIDE, 2020) discusses the implementation of infrastructure and the different estimates for hydrogen demand in NRW in 2030 and 2050. It estimates the demand of hydrogen in NRW in 2050 at 104TWh per year, where the biggest part will be consumed by the industry sector (40TWh). However, both mobility with 33 TWh and energy storage and conversion with 26TWh are also estimated to be important sectors for hydrogen demand in 2050[12]. The **carbon management strategy NRW** (MWIDE, 2021) discusses the potential use points for Carbon Dioxide in a circular economy, with a focus on the chemical industry, which needs carbon as a feedstock and the cement industry, which has process-imminent emissions, that can only be captured but not avoided. It discusses the interdependencies of decarbonisation, CCUS, and circularity and emphasises the necessity

[11] Currently, the production volumes and raw material input of the various sectors are not systematically recorded.
[12] Note that due to rapid developments in technologies on the supply side (plummeting prices for solar PV) and demand side, especially related to transport (uptake of EV markets) some of the projections contained in NRW government strategies appear to be obsolete and may be revised in the future.

of societal engagement and acceptance.

In North Rhine-Westphalia, and therefore also in the Rhine-Ruhr area, many different actors contribute to the discussions about decarbonisation, circular economy and sustainability in industrial sectors. Additionally to the strategies described above, the Ministry of economic affairs, industry, climate action and energy of the state of North Rhine-Westphalia, together with the Energy Agency of North Rhine-Westphalia, Energy4climate, coordinate the activities of the Think Tank IN4climate, which creates a platform for cooperation between all industry actors in NRW and is accompanied by a scientific consortium, consisting of the Wuppertal Institute, the Fraunhofer-Institute für Umwelt-, Sicherheits- und Energietechnik (UMSICHT), the Institut der deutschen Wirtschaft, the VDZ Technology gGmbH and the VDEh-Betriebsforschungsinstitut GmbH (BFI). More than 85 companies and associations from industry are participating in IN4climate. This includes the big steel and chemical companies, such as ThyssenKrupp and Covestro, but also infrastructure providers (airliquide, thyssengas, Currenta, OGE), energy companies (RWE, E.ON) and SME's from the region. Further, various scientific stakeholders and research organisations, as well as civil society and NGO's are involved in the discussion. For example, (Wilts, 2022) lists 88 activities at 39 universities in NRW that discuss circular economy aspects.

Overall, NRW in general and the Rhine-Ruhr region have embarked on the transformation towards climate neutrality and circularity. Institutions are in place to coordinate the process and key industry actors have taken investment decisions to lead the way. However, the starting point of the region is a challenging one and there is still a long way to go. As we shall see in the subsequent chapters, many uncertainties and knowledge gaps are hampering swift progress towards industrial transformation.

A.2.2 Insights of existing Models and Scenario-based Analyses

Germany and also the Rhine-Ruhr region, have seen significant efforts in modelling and estimating the effects of different transformation pathways toward a climate-neutral industry. On the national level, several studies model potential scenarios and pathways for decarbonisation in the industrial sector, employing bottom-up technological models, such as FORECAST and WISEE-EDM (Agora Energiewende und Wuppertal Institut, 2019; Herbst, 2022; Prognos et al., 2020, 2021), integrated assessment models and other tools. All of these studies show that decarbonisation is technologically feasible by 2050 or even 2045, but that significant challenges have to be addressed, and current efforts will not be enough.

Among others the following challenges for decarbonisation and circular economy are identified in several studies:

- Economic factors: High operational costs of carbon-neutral technologies, coupled with uncertainties surrounding large-scale investments, present significant barriers.
- Infrastructure: Developing the necessary infrastructure for a decarbonised economy, such as renewable energy grids and carbon capture storage facilities, is crucial but costly.
- Energy supply: Ensuring a reliable supply of carbon-neutral energy carriers is essential for a successful transition.
- Circular economy: Implementing circular economy principles, including recycling, material efficiency, and demand reduction, can significantly enhance resource utilisation but faces challenges like limited availability of secondary materials and product design constraints. Furthermore, the studies report data constraints and knowledge gaps regarding circular economy measures.
- Policy and regulatory frameworks: The development of effective policies and regulations to support decarbonisation and circular economy initiatives is essential, but often hindered by challenges like public capacity building and international cooperation.

While these studies offer valuable insights, they lack regional granularity, limiting our understanding of the specific effects on individual German regions. Additionally, while circular economy measures, such as recycling and material efficiency have been included in some of the studies mentioned above, research focusing solely on the circular economy has yet to fully leverage industry transformation models.

The Rhine-Ruhr region has been the subject of limited research in this area. While one study has examined regional petrochemical clusters using the WISEE-EDM model, it lacks in-depth analysis of decarbonisation scenarios. Regional stakeholders primarily rely on political strategies like hydrogen roadmaps and carbon management plans, highlighting the need for a more comprehensive and data-driven approach.

Table 7. Overview of selected studies on decarbonisation and circular economy measures in Germany and the Rhine-Ruhr area.

Title	Year	Region	Sectoral Focus	Focus	Model	Scenarios	Reference
Resilienter Klimaschutz durch eine zirkuläre Wirtschaft	2023	Germany	Steel, Cement, Chemicals	CE			(Agora Industrie & Systemiq, 2023)
Kreislaufwirtschaft in NRW – Überblick über zentrale EU-Maßnahmen und ihre Relevanz für NRW	2023	NRW		CE			(Bahn-Walkowiak et al., 2023)
Studie zur Circular Economy im Hinblick auf die Chemische Industrie	2017	NRW	Chemicals	CE			(Fraunhofer Umsicht, 2017)
Circular Economy in der Grundstoffindustrie: potenzial und Rahmenbedingungen für eine erfolgreiche Transformation	2021	NRW	Basic Industries	CE			(IN4climate.NRW, 2021)
Deutschland auf dem Weg zur Circular Economy	2019	Germany	General	CE			(Weber & Stuchtey, 2019)
NRW 2030: Von der fossilen Vergangenheit zur zirkulären Zukunft	2022	NRW	General	CE			(Wilts, 2022)
Kreislaufwirtschaft für eine klimaneutrale Industrie.	2024	Germany	Industry general	CE			(Denter et al., 2024)
Klimaneutrale Industrie	2020	Germany	Steel, Cement, Chemicals	Decarb	WISEE-EDM	Moderate High	(Agora Energiewende und Wuppertal Institut, 2019)
Pathways to a near carbon-neutral German industry sector by 2045: A model-based scenario comparison and recommendations for action	2021	Germany	Industry general	Decarb	FORECAST	Mix Electrification Hydrogen	(Herbst, 2022)
Industrial Innovation: Pathways to deep decarbonisation of Industry	2019	Germany	Industry general	Decarb	FORECAST	8 scenarios	(Chan et al., 2019; Fleiter et al., 2019)
Decarbonisation scenarios for the iron and steel industry in context of a sectoral carbon budget: Germany as a case study	2022	Germany	Steel	Decarb	Process Model	Reference Electrification Coal-exit; CCS	(Harpprecht et al., 2022)
Roadmap Chemie 2050	2019	Germany	Chemical Industry				(Geres, 2019)
The future potential hydrogen demand in energy-intensive industries - a site-specific approach applied to Germany	2022	Germany	Hydrogen Demand		FORECAST		(Neuwirth et al., 2022)
Simulating geographically distributed production networks of a climate neutral European petrochemical industry	2020	Europe	Chemicals Industry	Decarb	WISEE-EDM		(Schneider & Saurat, 2020)
Das petrochemische System in Deutschland und Westeuropa	2023	Germany	Chemical Industry	Decarb	WISEE-EDM		(Scholz et al., 2023)
Wege zu einer Netto-Null-Chemieindustrie – Eine Meta-Analyse aktueller Roadmaps und Szenariostudien	2023	Germany	Chemical Industry	Decarb	WISEE-EDM		(Kloo et al., 2023)
Studie zur Leistungsfähigkeit der NRW-Industrie und ihrer Transformation	2021	NRW	Industry general				(Prognos AG, 2021)
Sectoral Analysis of Energy-Intensive Industries	2023	Global	Emission-	Decarb			(Otto et al., 2023)

			intensive industries	& CE			

A.2.3 Insights from the Regional Stakeholder Workshop

To facilitate the workshop, the Three-Horizons facilitation method was used. In three rounds we discussed 1) the current situation of the industry in the Rhine-Ruhr area, 2) the future industry system that the participants envisioned, and 3) the how to achieve the future system. To conclude, participants were invited to give feedback on the workshop and the next steps in the project were presented.

A.2.3.1 Where are we now? What is the current industry system?

During the first session, participants were asked to describe the current industry system and why they think it is under pressure and has lost its fit regarding the current situation, and which obstacles hinder its transition to a more sustainable model. Participants unanimously recognised the system's unsustainable nature due to its linear structure, high emission intensity, and resource dependency. While the linearity and emissions were acknowledged as a common starting point, the discussion primarily focused on the specific barriers and problems hindering progress.

The prevailing uncertainty, stemming from geopolitical, regulatory, and economic factors, was identified as a key barrier discouraging investment. The expectation was formulated that the government should create stable and predictable framework conditions through credible regulation, be it about prices of energy and hydrogen, infrastructure or funding mechanisms. Furthermore, there is a lack of compelling business cases for green products, making government subsidies necessary and increasing firms' dependence on governmental regulation and action. Also, the bureaucratic burden was mentioned as a strong barrier regarding the transformation.

The transformation to green production processes requires massive investments in terms of new plants but also new infrastructure. This is further aggravated by the general (bad) economic situation and geopolitical competition which not only leads to an increasing investment backlog and bottleneck, both from the private side and from the governmental side, as only limited funds are available. It was mentioned as negatively affecting the acceptance of the transformation, overall.

The participants also discussed the impact of company structure on transformation pathways. While global companies take global investment decisions and thus create additional pressure on the local systems, SMEs are typically much more geographically rooted and do not relocate easily but rather close when they are not competitive anymore. Both scenarios create employment issues. At the same time, the lack of skilled workers is also perceived as a problem. Furthermore, many companies (esp. family-owned ones) are facing a generational shift as many entrepreneurs from the boomer generation are approaching the end of their career. One observation is that many smaller businesses have a hard time finding adequate successors to lead their operations. It is unclear how this generational shift will affect the transformation overall. On the one hand, the older generation may hesitate to start major transformation processes on the final stretch of their career. On the other hand, they typically have a very high level of attachment to their company having invested their entire careers. Meanwhile, the younger generation may have less attachment and therefore might hesitate from taking the burden to steer a company through a highly risky and very difficult transformation process. On the other hand, they might be more open to disruptive changes in their company's operations.

In general, it was mentioned, that the initial euphoria surrounding the green transformation has given way to disillusionment and realism. Participants emphasised the importance of concrete pilot projects to demonstrate the feasibility of the transition.

A.2.3.2 How does a vision for a future industry look like?

The second phase of the discussion focused on envisioning a future industry system. Participants emphasised the importance of strong European and regional value chains, as well as diversified global value chains and increased multilateral cooperation to reduce dependencies. Regarding the increasing pressure in the competition of systems internationally, participants took a normative stance stating that the preservation of the liberal, democratic order is essential.

The concept of sufficiency was discussed as a desirable goal for the future industry. Adaptability and flexibility in working conditions were seen as crucial for future success. On the one hand, companies need to provide flexibility to their employees in order to secure a labour force in an increasingly competitive labour market. On the other hands, technical requirements may require a flexibilisation of production processes and, as a corollary, labour e.g. to follow fluctuating renewable energy supply instead of maintaining a 24/7 production schedule. Furthermore, the development of infrastructure for green molecules and energy was identified as a key enabler for a more sustainable industry.

The discussion extended beyond regional considerations, acknowledging the need for rising global living standards and fair global resource sharing. Participants expressed a lack of understanding regarding how a more regional circular use of resources could enhance competitiveness and, crucially, resilience in the face of geopolitical uncertainties. The strong industrial clustering and interdependencies between sectors in the region were recognised as a major comparative advantage that should be preserved.

A.2.3.3 How do we get there?

The third session of the discussion focused on the strategies and challenges associated with achieving the envisioned future industry.

Participants expressed concerns that Germany, as an export-oriented economy, might be affected negatively by a changing global trade regime. The Carbon Border Adjustment Mechanism (CBAM) was discussed controversially, as there seemed to be a majority agreeing that the CBAM does not help the industry. On the one hand, there was some concern that the implementation of CBAM might prove to be ineffective. On the other hand, it the CBAM in its current form may protect the EU domestic market but will not compensate companies that export to third countries. Furthermore, societal acceptance was perceived as a major potential enabler, but also potential barrier for transformation.

Another key topic was the potential relocation of parts of the value chain and its potential chain effects on downstream industries. Participants debated whether such relocation could lead to a shift of downstream industries or whether focusing on efficient location based on energy supply conditions should be viewed positively.

A.3 Synthesis: Uncertainties and knowledge gaps

A.3.1 Key themes and uncertainties affecting the industrial transformation

Drawing on the insights generated in the stakeholder workshop and the existing literature, we highlight 5 main issues that affect the transformation of energy-intensive industries towards circularity and climate neutrality in the region.

Economic Viability and the Investment Backlog

A pervasive theme throughout the stakeholder consultations is the economic viability of decarbonisation. Participants repeatedly express anxiety about the high energy prices in Germany, which put them at a disadvantage compared to global competitors (Fraunhofer ISI, 2015). Of particular concern are prospective hydrogen prices. Especially for the steel industry, green hydrogen will be the primary fuel and reducing agent. While the development of the hydrogen infrastructure is picking up pace in the region, there is still no established market for green hydrogen and hence uncertainty about future prices remains high (Neuwirth et al., 2022). It seems that some industry actors are now entering a phase of hangover of what some have described a hydrogen hype. Investments in electrolysers are lower than anticipated and less progress is being made on the technological learning curve so that many industrial actors are now less optimistic about the future viability of hydrogen-based processes than just a few years ago (IEA, 2024).

This concern about future energy prices is exacerbated by the need for massive investments in new, decarbonised infrastructure (BCG et al., 2024; Draghi, 2024). Many current industrial assets are approaching the end of their technical lifetime and require urgent reinvestment. But for many decarbonisation technologies a universally accepted business model is lacking. Due to the many uncertainties (see below) related to the demand for green products and availability of low (enough) cost green energy and feedstocks these investments are in many cases “unbankable” – it is hard to convince a bank to provide a major loan for a product that does not have a market (yet). While some participants remain optimistic about long-term profitability, others voice reservations, emphasising the need for robust government support and clear market signals to incentivise investments in unproven technologies.

The investment backlog is also highly visible in the public sector. Germany’s infrastructure (especially railways, bridges but also digital public administration) is aging and requires massive public investments (Heilmann et al., 2024). However, after last year’s federal constitutional court decision to uphold the countries debt ceiling, participants are doubtful whether the German government still has the fiscal power to stem those investments. Consequently, they are concerned that the government will have to face tough decisions regarding how to spend scarce resources which might undermine fiscal support for the industrial transformation or thwart political stability overall if industrial transformation is prioritised over broader social policy issues. Here the key issue is to better understand the potential trade-offs that political and economic decision makers will have to face in a situation of limited fiscal investment capacity.

Changing geopolitical realities

One of the key concerns of participants emerges from Germany’s positioning as an economy. Participants shared concerns on how a changing global trade regime may affect German industry competitiveness. Currently, Germany still holds a significant industrial production of the first and most energy-intensive steps of basic raw material production in the industrial value chain. On the one hand, participants see this as a key advantage highlighting the strong cross-sectoral integration in synergistic clusters as a key competitiveness advantage. At the same time, they realise that regional energy prices in general and prices for green hydrogen in particular will hardly ever be competitive with other regions with more favourable conditions for large scale renewable energy supply. An alternative strategy might be to import intermediate products to outsource the energy- but not very labour-intensive part of the value chain to improve the competitiveness of later high-value added steps of the production chain. However, the key uncertainty or rather unknown is how much of the competitiveness advantage resulting from the clustering and cross-sectoral integration might get lost if individual steps of the value chain are relocated. In other words: which of the locational (dis)advantages dominates – higher energy prices or local network effects and synergies from cross-sectoral integration. A better understanding of what role secondary raw materials may play in mitigating some of the geopolitical effects outlined above may also provide helpful insights for more informed transformation strategies.

Besides, the stakeholders are acutely aware, bordering on anxiety, about the competitive threat posed by China. Participants acknowledge China's early and aggressive investments in green technologies, which have positioned them as a dominant player in the global market. Some participants argue that China's success is rooted in a more centralised, plan-driven approach, allowing them to scale up production and achieve cost advantages that are difficult for European companies to match.

This comparison with China fuels a debate about the role of government incl. the EU-level in driving industrial transformation. While some participants advocate for a more hands-off approach, emphasising market-driven solutions, others argue that the scale and urgency of the climate crisis demand a more active role for the state in shaping markets, setting clear targets, and providing financial support for key technologies. The challenge here is that Germany, being a heavily export-oriented industry, might hurt its own business model by engaging with trade-related measures to protect its domestic markets.

Navigating a Complex Web of Interdependencies

The stakeholders highlighted the intricate web of interdependencies that shape the decarbonisation challenge. Participants grapple with the global nature of supply chains, the need for international cooperation, and the risk of "carbon leakage," where emissions-intensive industries simply relocate to countries with laxer regulations (see also section 2.3.3. on CBAM). This global perspective underscores the need for a co-ordinated, multi-level approach to decarbonisation, involving governments, businesses, and civil society.

Discussions about the circular economy further illustrate this complexity. While participants generally agree on the importance of transitioning to a more circular model, they also acknowledge the practical challenges. Questions arise about the availability of sufficient quantities of high-quality secondary materials, the need for new infrastructure and technologies, and the importance of shifting consumer behaviour towards more sustainable choices. Higher level "r-strategies" such as remanufacturing and extending the lifespan of products (repair and reuse) are hopeful options, but the potential of these approaches to reduce the need for primary production and contribute to decarbonisation efforts remains largely unknown. What is clear, though, is that there is need for regulations and incentives to encourage these practices (Denter et al., 2024).

Realising the full potential of the circular economy will require a systemic shift, encompassing not just technological innovation, but also regulatory changes, business model innovation, and public awareness campaigns.

A potential driver for transformation may be the fact that enhanced circularity may foster resource security, particularly crucial in a world grappling with volatile global supply chains and potential geopolitical disruptions (Agora Industrie & Systemiq, 2023). However, it remains unclear what effect closed material loops may have on supply chain resilience and raw material prices.

The Human Factor: A Critical Element

Furthermore, participants underscore the importance of the human factor in industrial transformation. They repeatedly emphasise the need to address the social implications of decarbonisation, including the potential for job losses, the need for reskilling and upskilling programs, and the importance of ensuring a just transition for workers. The discussion reveals a keen awareness that the success of NRW's industry transformation hinges not only on technological innovation, but also on securing the support and participation of the workforce.

The role of labour unions and worker representation emerges as a critical element in this transition. Participants discuss the importance of involving workers in the decision-making process, ensuring their voices are heard, and addressing their concerns about job security and working conditions in a decarbonised economy. This focus on the human dimension underscores the understanding that a successful industrial transformation requires not only technological solutions, but also a commitment to social dialogue, fairness, and equity.

On the other hand, stakeholders highlighted the challenges associated with demographic change which may result in a shortage of skilled labour which is not only felt at the level of the plant but also in the management offices as many SMEs including many family entrepreneurs face challenges finding adequate successors that are willing to steer the company through a tremendously challenging transformation process.

Seeking Clarity Amidst Uncertainty

A key concern raised by stakeholders is the increasing levels of uncertainty that hamper key investment decisions. This uncertainty pertains to several dimensions: technological uncertainty, economic uncertainty and political uncertainty. Given the state of technological readiness of several key green technologies, industrial stakeholders still face significant knowledge gaps regarding which technologies will work technically, how steep learning curves will be and how fast technologies can be improved in terms of efficiency and cost effectiveness. This challenge is particularly pronounced in the chemical industry where it is not known yet which of the potential alternatives such as synthetic feedstocks, biogenic feedstocks or (chemical) recycling will be most viable. In the steel sector, the outlook is clearer with all major investments going towards hydrogen-based steelmaking. Yet, many of the steel companies had hedged their bet on green hydrogen as the new DRI plants are typically also capable on running on natural gas. This would have allowed to gradually phase in hydrogen as it becomes available. Now with significantly higher natural gas prices resulting from Russia's invasion of Ukraine, this fallback option is much less attractive economically, again exposing steelmakers to the full uncertainty related to the hydrogen economy.

Industry is facing economic uncertainty at least on two levels. The energy crises resulting from Russia's war on Ukraine has led to an energy price shock. Prices for natural gas and electricity skyrocketed exceeding what actors had perceived to be the upper limits of their worst-case scenarios. As a result, investors now must consider a much wider range of potential energy prices than before the energy crisis. On the other hand, global markets for energy-intensive raw materials including steel and basic chemicals are in turmoil. The slump of the Chinese construction industry has dramatically increased the problem of global overcapacities in the steel industry. In the chemicals industry major (state-owned) corporations from the Middle East are aggressively expanding their global business. For instance, ADNOC, the state-owned petrochemical giant from the United Arab Emirates, is in the process of taking over German polymer manufacturer Covestro.[13]

Finally, political uncertainty relates mostly to the recent surge of far-right populist parties across Europe. With political pressures rising, industrial stakeholders seem to be questioning how resolved and resilient European energy and climate policy is. It no longer seems impossible to roll back or at least soften key

[13] https://www.covestro.com/press/covestro-signs-an-investment-agreement-with-adnoc-and-supports-adnocs-public-takeover-offer-to-all-covestro-shareholders/

policies like the EU ETS before the eventual end of allocating new emission allowances in 2038. Moreover, the recent ruling of the German federal constitutional court to limit the German governments spending has raised concerns about the state's ability to sustain its support for the transformation of industry over the long run. Hence, there is an increasing perception of uncertainty related to the political framework conditions in which companies will have to build and operate new green industrial processes.

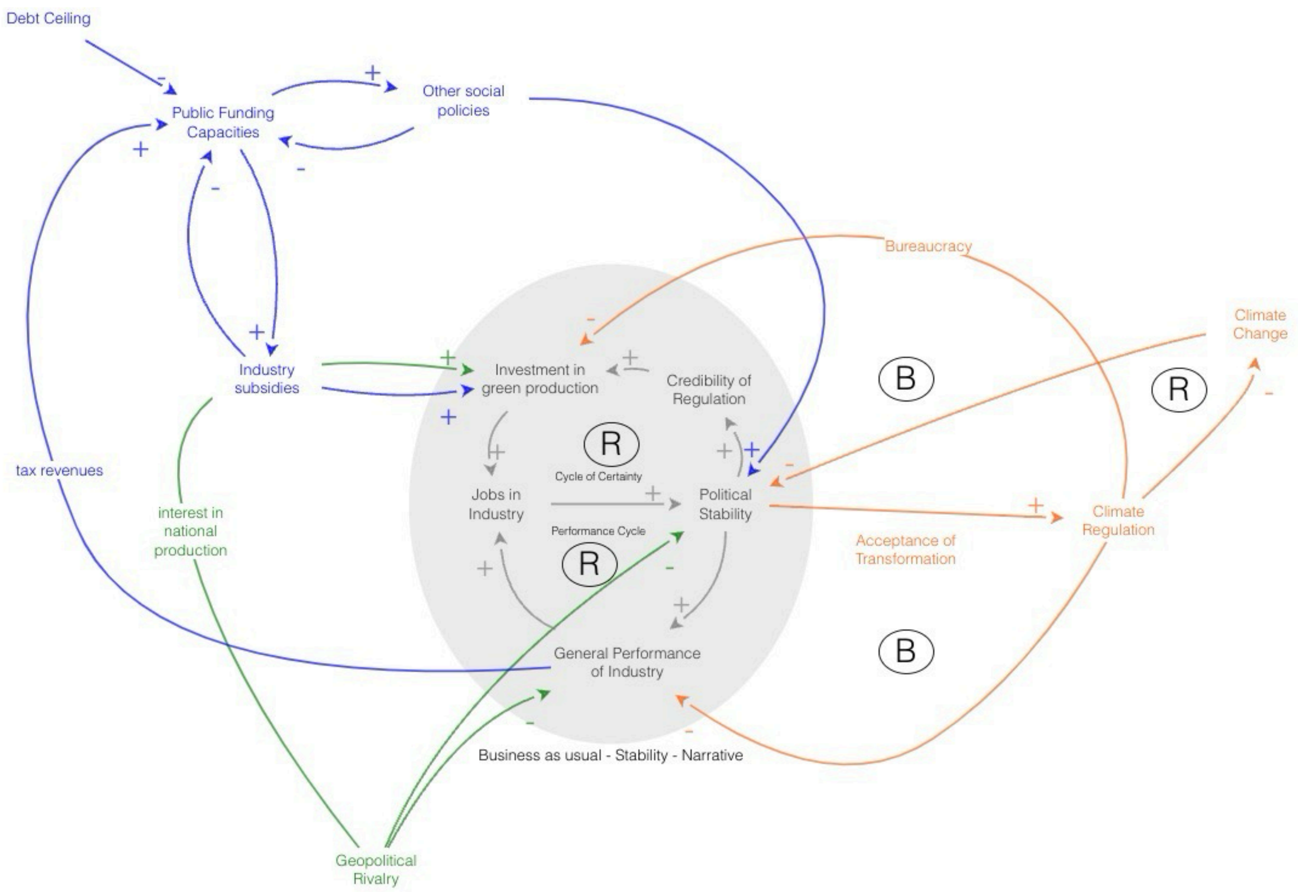


Figure 9 **Causal map illustrating the interdependencies which result in a vicious circle of increasing uncertainty which, in turn, is hampering transformative investments in the Rhine-Ruhr Region.**

While the above account is certainly not exhaustive, it contextualises several of the major challenges, drivers and barriers for industrial decarbonisation identified in the case study. Table 8 below provides a more comprehensive but less detailed overview of the identified challenges.

Table 8. Overview of key challenges, drivers and barriers identified in the Rhine Ruhr Case Study.

Key word	Challenges	Drivers (+) /Barriers (-)	Type*	Dimension**
Uncertainty	Prevailing **uncertainty**, stemming from geopolitical, regulatory, and economic factors	Delays complicate investment decision on the company level (-); Government should create stable and predictable framework conditions (+); Political support for the transformation is challenged (-)	P / E	D
Regulation	Stable and predictable **framework conditions**, be it about prices of energy and hydrogen, infrastructure or funding mechanisms.	Credible regulation can be a key driver of transformation (+); Credibility is challenged by the time horizon of political decisionmakers, making time inconsistencies more probable (-);	P	D
Business Case	Need for a **business case** for green products	Government subsidies are necessary but increase firms' dependence on govern-mental regulation and action (-); Green lead markets, Carbon Prices and Sheltering from international competition can create demand (+);	E	D
Energy/ Electricity	Need for **electrification, stable energy prices** and good locational conditions	high energy prices (-); subsidies for industrial electricity prices (+)	E	D
Bureaucracy	Need for **effective bureaucratic structures**, enabling regulation & efficient monitoring	Public sector capacity is generally high (+); Bureaucratic burden can hinder investment (-)	C / P	D
Limited funding capacity	Green production processes require massive **investments** in terms of **new plants and new infrastructure**	only limited funds are available, partly due to the general (bad) economic situation (-); Subsidies for green transformation, e.g.IPCEIs (+)	E	D
Skilled workers	Need for **skilled workers**	Lack of skilled workers (-)	C	D / CE
Company structure	**Generational shift** in family-owned businesses; **Global companies** with limited locational commitment	Potential hesitation to take over the business and steering a company through a highly risky and very difficult transformation process (-); Higher openness transformational change in younger generations (+); Global companies take international business decisions; potential carbon leakage (-)	C	D / CE
Acceptance & Public Perception	Need for **acceptance** of the transformation	concrete pilot projects to demonstrate the feasibility of the transition (+); democratic processes and engagement possibilities for different stakeholders (+)	C	D / CE
Resilience	Need for **diversified and resilient value chains**	strong European and regional value chains (+); Dependency from China (-)	N	D / CE
Clustering and regional integration	strong **industrial clustering** and interdependencies between sectors in the region	Interdependencies as strong regional competitive advantage (+); At the same time barrier for individual transformation efforts (-)	N	D / CE
Recycling as Circular Economy	Public perception, as there is **limited understanding of the circular economy**, often conflated solely with recycling	No use of higher R-strategies (-)	C	CE
Level Playing Field	Carbon Border Adjustment Mechanism **(CBAM)** to incentivise decarbonisation and level the playing field with countries that have less stringent environmental regulations	Need for a more unified European market approach, including measures to protect European industries from climate dumping and ensure a stable demand for green products	E / P	D
Recycled Materials	Higher **recycling percentages** to alleviate resource constraints and establish circular economy	Minimum recycling quotas (+); Low demand for recycled materials (-); Low availability of high-quality recycled materials (-); Changes in material flows, affecting the synergies in the clusters (-)	P/E	CE

*** Types: Political (P), Economical (E), Technological (T), Capacity/Awareness (C), Network (N)**
**** Dimension: Decarbonisation (D), Circular Economy (CE), Sustainability (S)**

A.3.2 Opportunities for enhanced modelling tools

Clearly, the modules currently under development for the MIC3 ecosystem will not be able to contribute insights to all the issues listed above. For instance, issues related to demographic change and the challenges of transferring leadership are in all likelihood not amenable to model-based analysis. Others, still, point towards interesting challenges regarding new models and enhanced scenario work. In this section we will highlight insights from the stakeholder engagement that may constructively challenge the model development in subsequent TRANSIENCE research.

Addressing a much broader range of trade and energy futures: The recent energy crisis and Russia's war on Ukraine have unmasked a level of risk and uncertainty that was previously not perceived by stakeholders. Future models should be able to model more extreme scenarios including some that include supply shocks in relation to key technologies and raw materials. Industrial stakeholders have started to value resilience in their operations over one-dimensional cost effectiveness. In order to devise their long-term transformation strategies, they need to take low probability high impact scenarios into consideration. For TRANSIENCE this may mean to develop a suite of security and resilience focused scenarios and ensure that the models are able to meaningfully implement those scenarios in the first place.

Enhancing the understanding of the benefits of circularity for resilience and competitiveness: To date, no model-based analyses of pathways towards circularity exist at the regional level. Moreover, given the perceived increase of risk related to the availability and affordability of scarce resources, many stakeholders have expressed hopes that more effective recycling of materials can improve resilience and reduce Europe's dependence from global commodity markets with highly volatile prices.

Improving the representation of higher R-strategies: During our conversations with stakeholders, we frequently observed "short circuiting" of the circular economy debate towards recycling. This is, perhaps, the most tangible aspect of the circular economy concept and one that is fairly straight forward to model. However, many of the higher-level r-strategies (refuse, reduce, reuse, repair, remanufacture) are less amenable. A better representation of these strategies in models and enhanced understanding of their respective contribution might help to avoid this short circuiting and help accelerate the transformation towards circularity.

Understanding the effects of constrained capital for public and private investments: Rhine Ruhr stakeholders were concerned about the limitations of funding available to support investments. State coffers seem more constrained than ever. Future analysis should allow to better understand the trade-offs between different investments and allow to devise strategies to achieve optimal results with limited CAPEX resources.

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Annex B: Basque Country Regional Case Study

Iñigo Muñoz, Diego García-Gusano, Izaskun Jiménez, and Hanna Kuittinen

B.1 Introduction

Aiming for co-creative, transdisciplinary, and participatory modelling science, the development of the MIC3 integrated modelling framework within TRANSIENCE entails the reinforcement of stakeholders' role through the whole modelling and policy-making processes. Indeed, TRANSIENCE will work together with key stakeholders from policy, industry, society, and research in an iterative co-creation process developing a dynamic, two-way stakeholder feedback process that ensures stakeholders are actively engaged in the various stages and the modelling outcomes truly match their needs. Considering the divergence between the outputs of the state-of-the-art strictly formalised model frameworks (e.g., IAMs or CGE models) and the real-life policy and industry context in which decisions are taken, this initiative draws heavily on the active involvement of the most relevant stakeholders (including but not limited to industry actors, regional/national governments and associated governmental agencies, sectoral cluster associations, academia, and citizens), not only in terms of co-designing scenarios and identifying pertinent questions but also in co-developing the new model capabilities themselves. A fruitful dialogue with different stakeholders is a vital first step to meaningfully enriching modelling capacity in the light of modern challenges, without favouring specific approaches[14].

To this end, TRANSIENCE targets the engagement of relevant stakeholders, the co-identification of gaps, challenges, and opportunities in both modelling and real-world industry contexts towards the enhancement/creation of existing/new modelling capacities that will satisfy the requirements of the latter, and finally the co-design of scenarios and validation of the MIC3 framework.

Throughout the whole project workshops will be used for collecting insights that will enrich, and should be covered by, the modelling framework. During the different phases of the project, regional workshops will be held in the selected four major industrial clusters in Europe that are used as case studies: Basque country, Port of Rotterdam, Rhine-Ruhr, and Silesia. Parallelly, discussion roundtables will take place in Brussels to align regional results with EU policy and to share the different perspectives. Altogether, these series of workshops will seek to identify the knowledge gaps and research questions to which MIC3 can respond, to collect insights on industry real-world problems and requirements, to validate the modelling framework developments, and to demonstrate MIC3 capabilities through the development, modelling, and assessment of co-created industrial transformation scenario narratives.

In the first stage of stakeholders and capacity needs identification, the dialogue amongst stakeholders has served for the identification of the main factors and elements impacting in the decarbonisation, circularity, and sustainability of the industries within each region. This report summarises the main comments, suggestions, concerns, opinions, and ideas that emerged in the discussion of the first Basque Country regional workshop. The workshop utilised "Three Horizon" facilitation method[15] that provided a framework for analysis three interconnected horizons: the prevailing present ("Where are we now?"), the emerging future ("Where do we want to go?"), and the transition ("How do we get there?". The workshop was organised in

[14] EERA - European Energy Research alliance (2023) Vision paper: Towards a more collaborative energy system modelling for addressing Europe's energy transition challenges. Available: https://www.eera-set.eu/activities/research/publications.html#collapse-item-2
[15] Sharpe, B., Hodgson, A., Leicester, G., Lyon, A., & Fazey, I. (2016). Three horizons: A pathways practice for transformation. Ecology and Society, 21(2). https://doi.org/10.5751/ES-08388-210247

28th of May 2024 and gathered 10 key experts of the regional industry.

In addition to presenting the workshop findings, the report presents the region in terms of industrial capacities to describe background information for the case study, justifying why the industrial transformation is relevant for the Basque Country region and to identify key industrial clusters in the region.

The remaining of this report is structured so that the background study is presented in Section B.2 of this annex. Section B.3 presents the approach for the workshop and Section B.4 presents the key insights gathered during the workshop. Section B.5 discusses the findings in terms of cross-sectoral linkages, whereas Sections B.6 and B.7 synthetise the findings from the perspectives of uncertainties and knowledge gaps, and key transformation challenges, respectively.

B.2 Background

B.2.1 Description of the region

The Basque Country has a large industrial tradition. Located on the north shore of Spain, the region historically concentrated heavy industries such as iron production, shipbuilding, and steelmaking. In the late 20th century, the Basque Country underwent a major transformation towards a more service-oriented economy due to the urge of tackling the decline of iron production and shipbuilding. Nevertheless, industry sector still has a significant influence in the Basque economy with a relevant traditional industry (with steel, foundries, refinery, cement, and paper companies) and a large number of firms focused on machine tool, automotive, advanced manufacturing, and aerospace amongst others.

In 2022 industry represented 22% of Gross Value Added (GVA) (Figure 8) within the Basque economy (24% if the energy sector[16] is accounted too), which makes the region productive structure more similar to the German than to the Spanish or French one. Concerning employment, industry was the second sector with the highest employment (Figure 9), just behind the services sector. Around 19% of the working population was employed in the sector.

[16] The energy sector accounts for processes where energy is transformed such as power plants or refineries.

Funded by the European Union

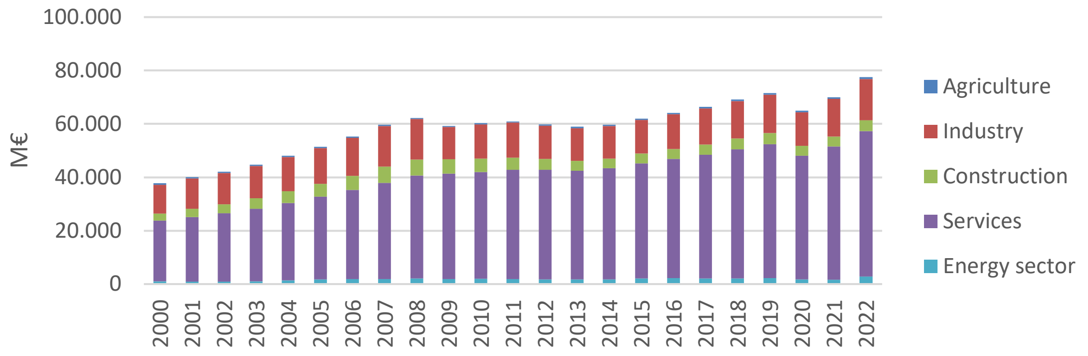

Figure 10. Gross Value Added in the Basque country by economic sector. (Source: EUSTAT).

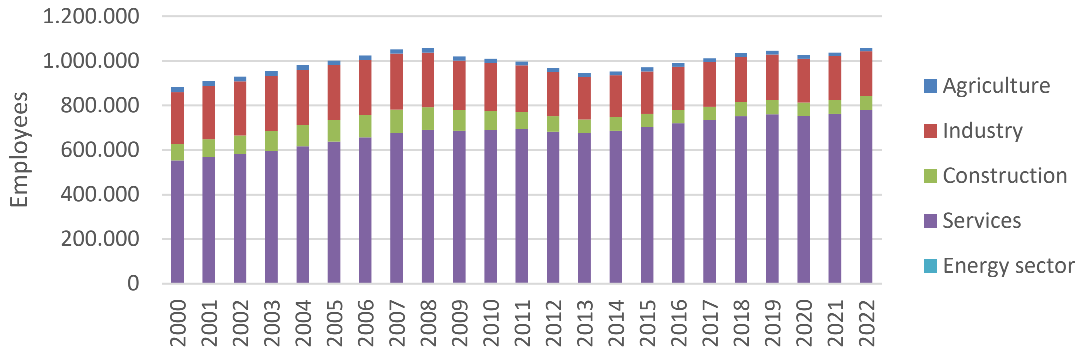

Figure 11. Employment in the Basque country by economic sector. (Source: EUSTAT).

With regards to energy consumption (Figure 10) and GHG emissions (Figure 11), industry has been overtaken by transport as the most consuming and pollutant sector. Indeed, industrial final energy consumption has fallen from almost 50% of final energy consumed in the Basque Country in 2000 to 35% in 2022. In GHG emissions terms the picture is similar with industry emissions having reduced from 46% to 30% of regional GHG emissions (59% to 42% if energy sector is accounted too).

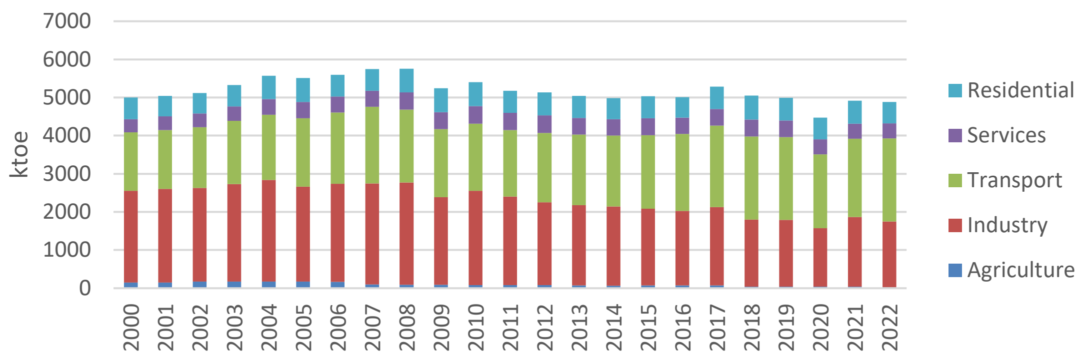

Figure 12. Final energy consumption in the Basque Country by end-use sector. (Source: EVE).

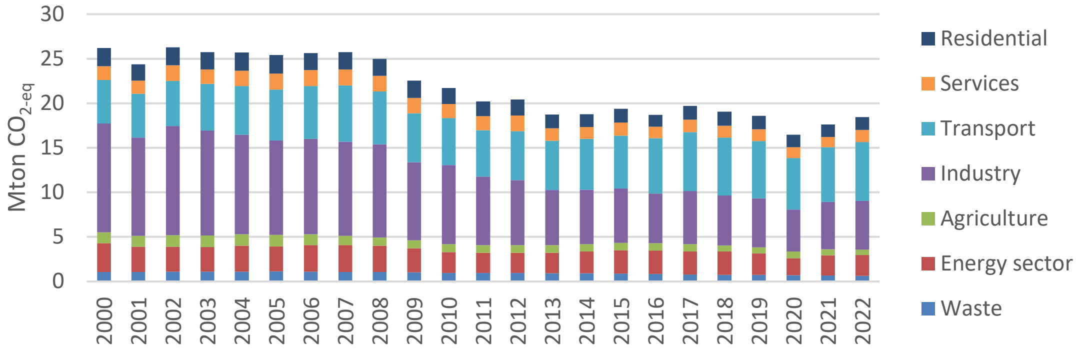

Figure 13. GHG emissions (scope 2) in the Basque Country by sector. (Source: IHOBE).

In the last years, reduction in industry energy consumption can be explained in part by the improvement of industrial energy intensity. Indeed, although industrial GVA has continued growing, energy consumption has declined as shown in Figure 12. This could be the implicit result of the deployment of different energy conservation measures in the last years that have contributed to the improvement of industrial energy efficiency. Along with the reduction of energy consumption itself, decrease in industrial GHG emissions may be explained to changes in the fuel mix (Figure 13). In the last years, solid fuels have been replaced by natural gas and oil products while renewable contribution has doubled its share (although remains low). The decarbonisation of the national grid has also contributed to the abatement of the industry GHG emissions. Altogether there is still work to be done to transform Basque Country into a climate-neutral economy.

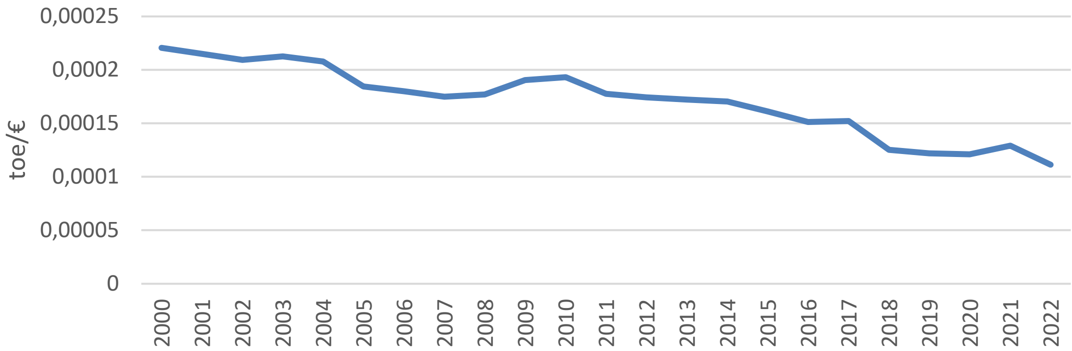

Figure 14. Industrial energy intensity (industry energy consumption/industry GVA) in the Basque Country. (Own elaboration based on data provided by EUSTAT).

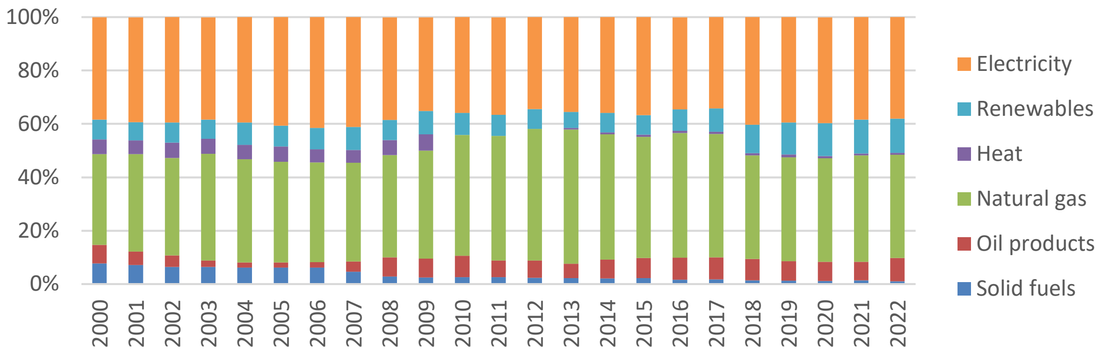

Figure 15. Industry energy mix evolution. (Source: EVE).

Given this context, the Basque Country, and specifically the Basque industry, is committed to reduce its environmental impact. On this matter, the Basque government has set a framework for the decarbonisation of the region with the 2019 sustainability law[17,18], 2030 energy strategy[19], and 2050 climate change strategy[20]. These documents include measures seeking to foster the competitivity and sustainability of the Basque industry such as the implementation of energy efficiency and management solutions in industrial processes, the phase out of liquid fossil fuels by 2030, or the deployment of RES amongst others. In parallel, the new energy transition and climate change law[21] establishes the guiding tools for achieving carbon neutrality by 2050: the 2050 Long-Term Energy Transition and Climate Change Roadmap and the 2030 Energy Transition and Climate Change Strategy, which are currently under development. Concerning the industry sector, the law aims to promote decarbonisation and circularity actions within the sector.

Under this framework, different initiatives have emerged in the last years aiming to decarbonise and improve the circularity of the Basque industry. On the one hand, the *Basque Net Zero Industrial Super Cluster* (NZBIS)[22], supported by the public administration, industrial clusters, and leading energy companies, aims to foster the decarbonisation of Basque industries creating market opportunities based on innovative solutions. This initiative is a part of the World Economic Forum project *Transitioning Industrial Clusters towards Net Zero*[23]. On the other hand, focused on promoting industrial synergies, the *Basque Industrial Hub for Circularity* (BIH4C)[24] targets the transformation of existing industrial areas through the search for and implementation of energy synergies, the efficient use of resources and technological innovation.

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[17] Law 4/2019, of February 21, on energy sustainability of the Basque Autonomous Community Basque. Summary available: https://leyvascasostenibilidad.es/

[18] General Provisions, 1087, Law 4/2019, of February 21, on Energy Sustainability of the Basque Autonomous Community, Official Bulletin of Basque Country https://www.euskadi.eus/bopv2/datos/2019/02/1901087a.pdf

[19] Energy Agency of the Basque Government (2017) Basque Energy Strategy 2030. Available: , https://www.eve.eus/EveWeb/media/EVE/pdf/3E2030/EVE-3E2030-castellano.pdf

[20] Basque Government (2015) Basque Country Climate Change Strategy 2050. Available: https://bideoak2.euskadi.eus/debates/debate_1310/Estrategia_cambio_climatico_clima_2050_es.pdf

[21] Law 1/2024, of February 8, on Energy Transition and Climate Change. Available: https://www.legegunea.euskadi.eus/eli/es-pv/l/2024/02/08/1/dof/spa/html/webleg00-contfich/es/

[22] The Basque Business Development Agency (2024) Net-Zero Basque Industrial Super Cluster. Website available: https://www.spri.eus/es/ayudas/net-zero-basque-industrial-super-cluster/.

[23] World Economic Forum (2023) Transitioning Industrial Clusters towards Net Zero. Report available: https://www.weforum.org/publications/transitioning-industrial-clusters-towards-net-zero/

[24] Basque Energy Cluster (2024) The Basque Industrial Hub for Circularity is born: an innovation hub for the decarbonisation of the Basque industry. Associated news, 30th of January 2024. Available: https://www.clusterenergia.com/noticias-asociados-2/nace-basque-industrial-hub-for-circularity-un-hub-innovacion-para-descarbonizacion-industria-vasca

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B.2.2 Justification of case selection

The Basque Country gathers an important number of industrial companies and firms from diverse kind, ranging from traditional industries such as steel, foundry, cement, and paper, to more advanced manufacturing like machine tool, automotive, and aerospace amongst others. All these firms and industries are usually associated in sectoral clusters[25], amongst which the following stand out: steel cluster, foundry cluster, paper cluster, advanced manufacturing cluster, automotive cluster, and food cluster. Besides the traditional manufacturing sectors, the region hosts one of the major refineries in Spain (included above in the energy sector).

This relevance of the industry sector in the region is also supported by the presence of several institutions and important stakeholders which objective is to promote industrial development. These include the Basque agency for industrial and enterprise development (SPRI), the Basque Energy Cluster, the Basque Environmental Cluster, the energy and environmental governmental agencies (EVE and IHOBE respectively), and several research organisations amongst universities and technological centres. Finally, besides big industrial companies, the Basque Country has a long tradition in industrial cooperatives gathering companies of diverse sizes and focused on different fields like advanced manufacturing or automotive.

Amongst the different industrial sectors present in the region, the most energy-consuming ones in 2021 were steel & foundry, pulp & paper, machinery & manufacturing, cement, and chemical, representing respectively 30%, 17%, 10%, 8%, and 7% of total industrial energy consumption (see Figure 15). Amongst steel & foundry and machinery & manufacturing, natural gas and electricity are the main consumed fuels as shown in Figure 14. Solid fuels are still present in the steel industry, mainly used as raw material for processes. Solid fuels are nevertheless used extensively in the cement industry for heating applications, with its replacement rate by renewables still very low. On the contrary, the pulp & paper industry uses process and forestry waste (mainly black liquor and biomass respectively) to increase the renewable contribution up to a third of the sector energy mix.

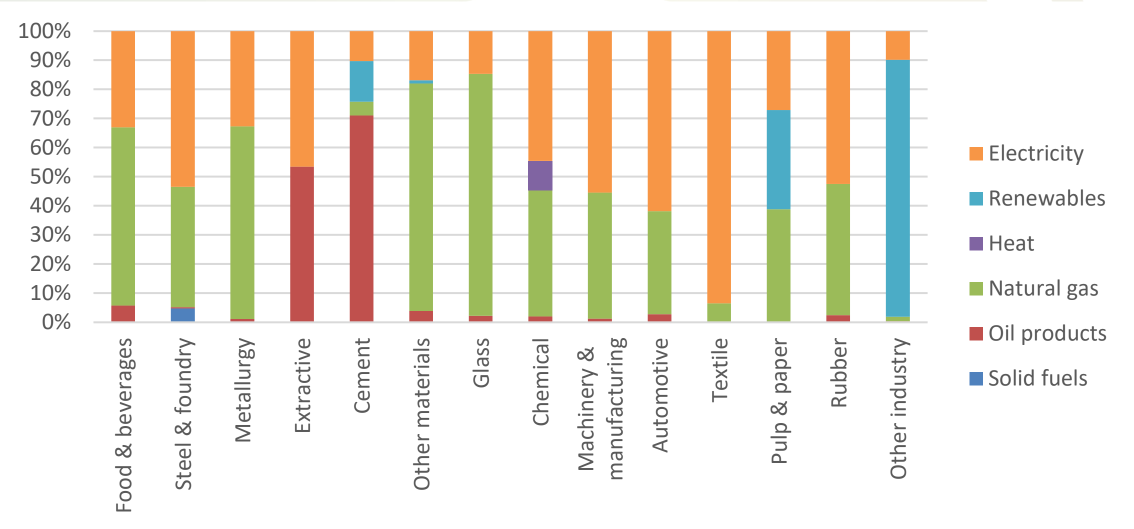

Figure 16. Energy mix by industrial sector in the Basque Country. (Source: EVE).

[25] The Basque Business Development Agency (2024) Cluster Policy – Promoting technological and business collaboration between sectoral companies. Website available: https://www.spri.eus/es/ris3-euskadi/politica-de-clusters/

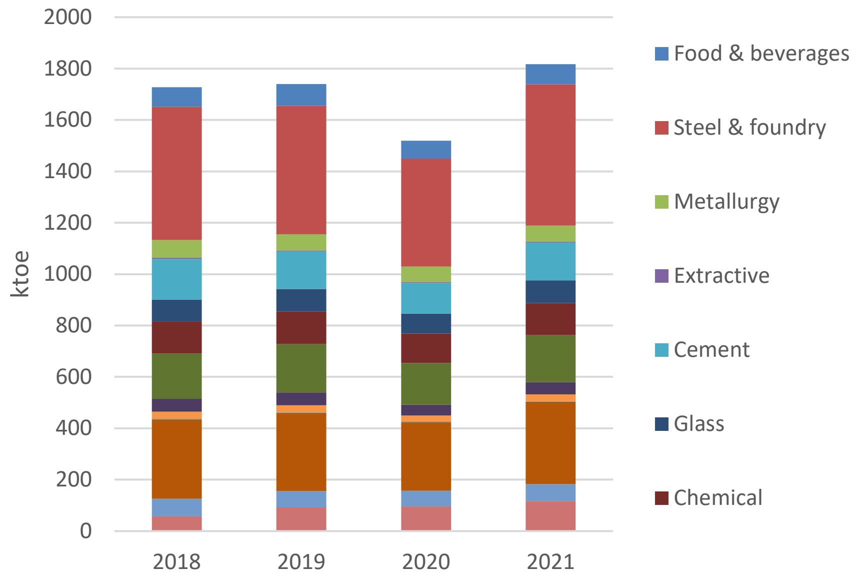

Figure 17. Industry energy consumption by sector in the Basque Country. (Source: EVE).

In GHG emissions terms however, cement was the most pollutant sector with a 27% share (considering process emissions too) of total industrial emissions, followed by the steel industry (26%), pulp & paper (9%), and machinery & manufacturing (8%) as shown in Figure 16. Altogether, process emissions represented 28% of total GHG emissions from industry in 2021.

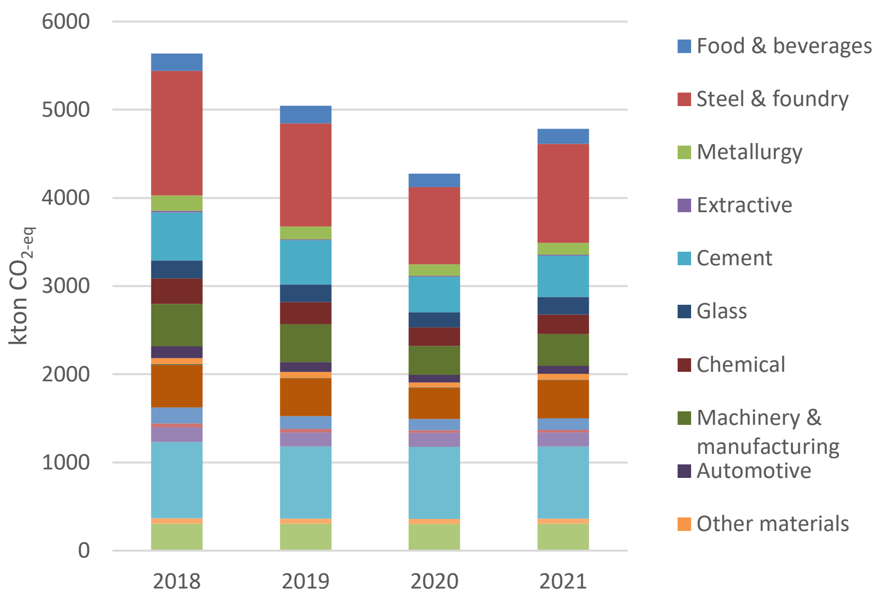

Figure 18. Industry GHG emissions (scope 2) by sector in the Basque Country. (Own elaboration).

Nevertheless, if the oil refinery emissions are accounted alongside industry emissions, oil refining becomes the most pollutant sector with 1,747 kton $CO_{2\text{-eq}}$ emitted in 2021 (see Figure 17).

Given these figures, steel & foundry, cement, pulp & paper, and machinery & manufacturing, with oil refining from the energy sector, play a key role in the decarbonisation of the region. Actions should be prioritised in these sectors to fulfil the climate objectives of the region, without forgetting the process emissions spread over other smaller sectors.

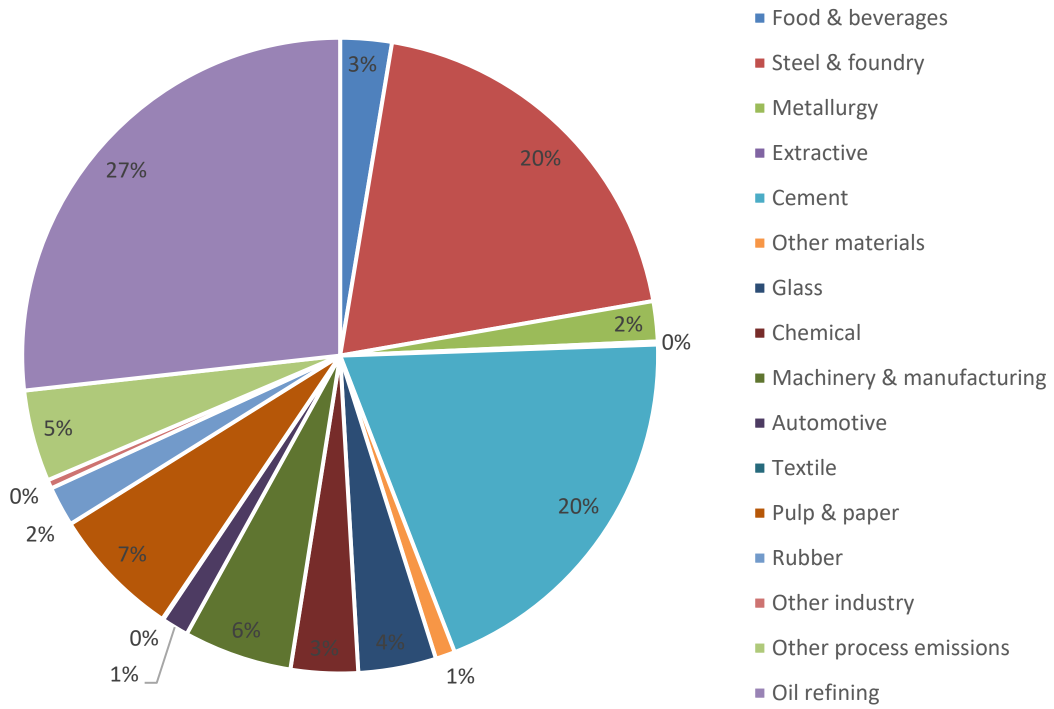

Figure 19. Industry plus oil refining GHG emissions share (scope 2) in 2021 in the Basque Country. (Own elaboration).

B.2.3 Key industrial clusters in the region and their relevance

Focusing on the identified key industrial sectors, machinery & manufacturing is the sector that contributes the most to the economy of the region, as shown in the Figure 18 in respect to gross value added and Figure 19 in respect to employment. In 2021 the sector billed almost 6,000 M€ and employed 90,000 workers. Steel & foundry is the second sector in terms of GVA (1,726 M€), closely followed by the automotive sector (1,644 M€) that, although not identified as a priority sector in terms of decarbonisation needs, is the second sector with the highest employment level. Pulp & paper and cement sectors, despite their energy and environmental impact, do not have a significant weight in the regional economy. Lastly, oil refining, with only one plant in the territory, had a significant turnover in 2021 (1,077 M€) but only employed 900 workers.

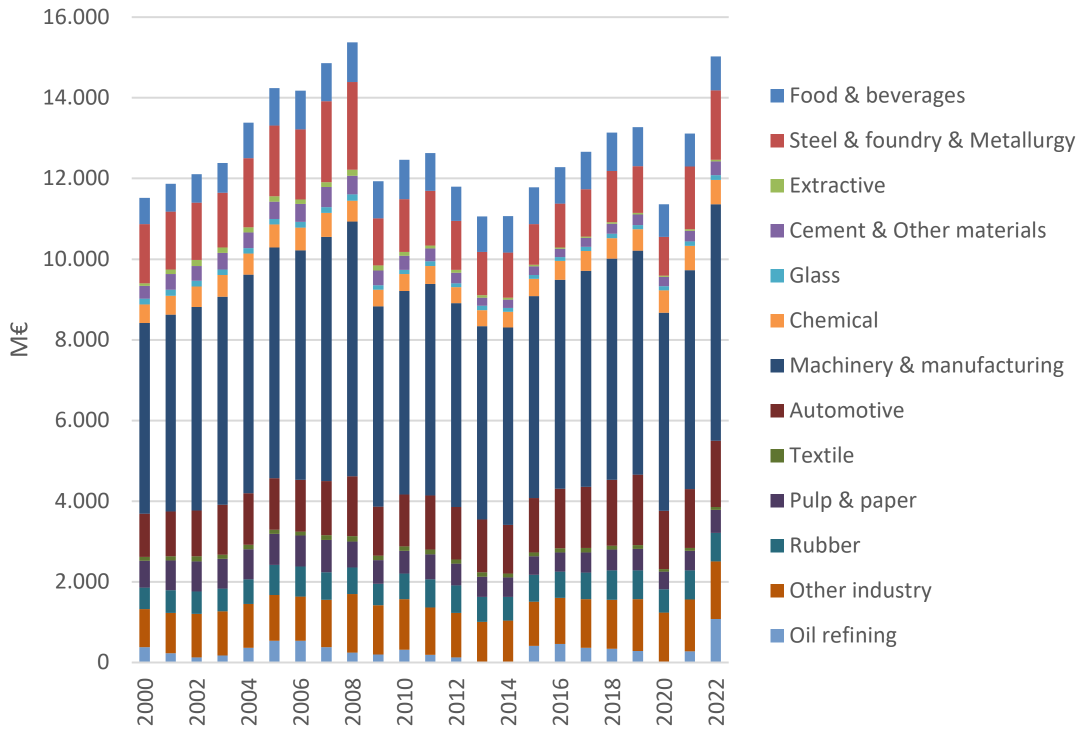

Figure 20. Gross Value Added amongst oil refining and industrial sectors in the Basque Country. (Source: EU-STAT).

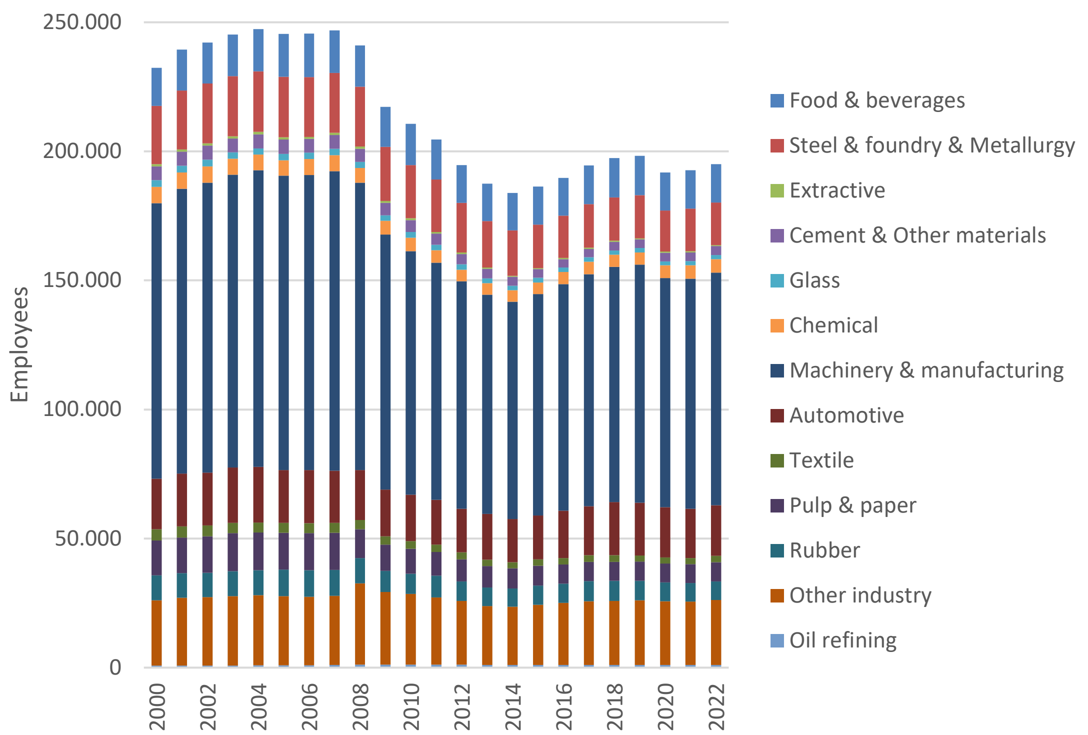

Figure 21. Employment amongst oil refining and industrial sectors in the Basque Country. (Source: EUSTAT).

Finally, combining reported GHG emissions and GVA (see Figure 20), the emission intensity of the different sectors and its evolution can be assessed. Oil refining (7-6 kton $CO_{2\text{-eq}}$/M€) and cement (6-5 kton $CO_{2\text{-eq}}$/M€) are the most emission-intensive sectors by far. Steel & foundry and pulp & paper have a similar emission intensity (around 1 kton $CO_{2\text{-eq}}$/M€) while the machinery & manufacturing sector has one of the lowest emission intensities of the whole industry (0.09-0.07 kton $CO_{2\text{-eq}}$/M€). The case of the glass sector should be noted and is that even not being classified as a priority sector, its emission intensity is one of the highest (2.5 kton $CO_{2\text{-eq}}$/M€). All in all, following the declining trend of the energy consumption and emissions in the industry sector, the emission intensity of the key industries for the region decarbonisation has decreased in the last years. In some sectors, such as automotive or pulp and paper the decrease of emission intensity has however been rather marginal in 2018-2021.

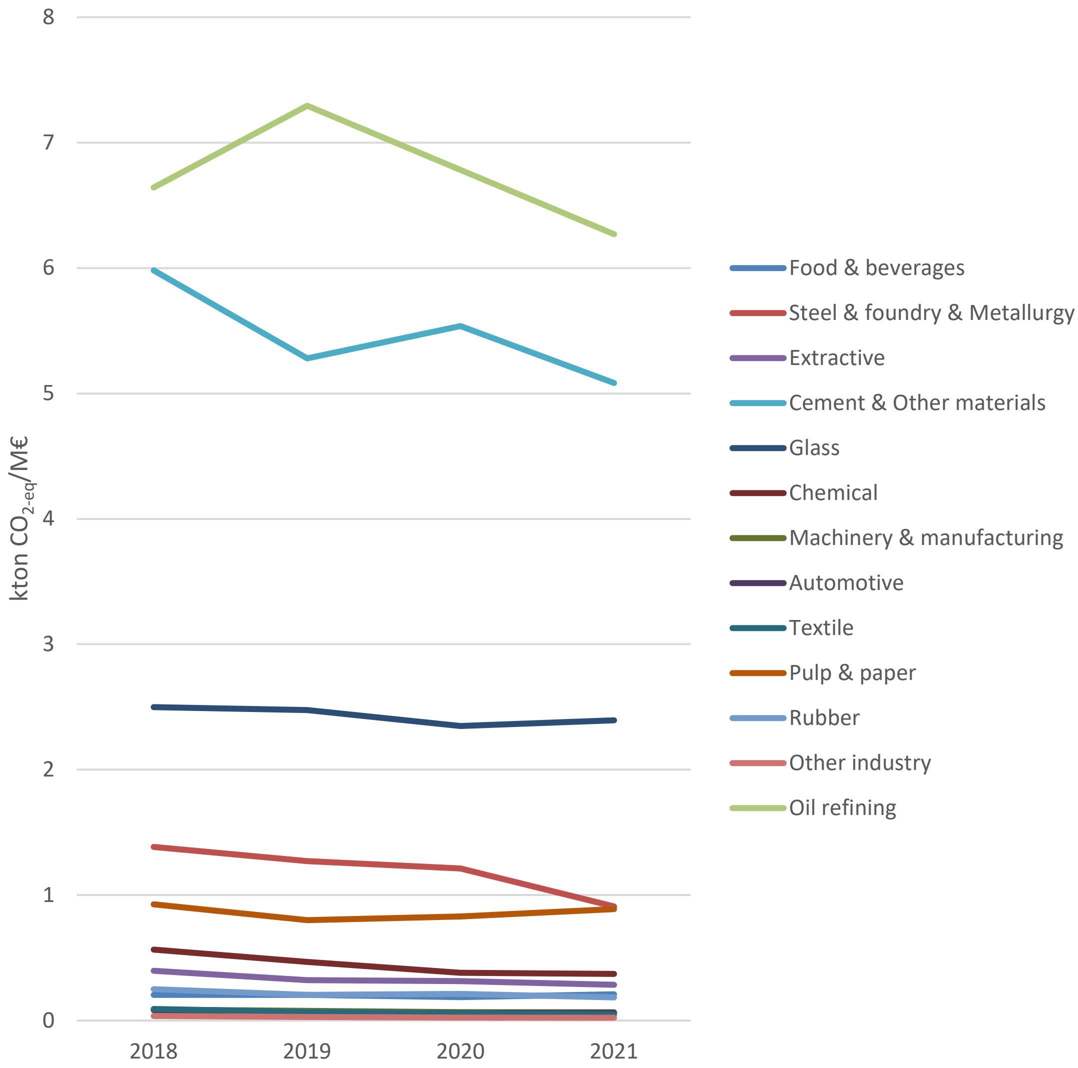

Figure 22. Emissions intensity (emissions/GVA) per sector in the Basque Country. (Own elaboration).

B.3 Case Study Method

B.3.1 Approach for the regional workshop

The first regional workshop of TRANSIENCE was organised at TECNALIA's premises in Zamudio 28th of May 2024. It gathered 10 key experts of the regional industry, including participants from the Basque Centre for Climate Change (BC3), Basque Energy Cluster (ACE), Basque Environment Cluster (ACLIMA), Energy Agency of the Basque Government (EVE), Mondragon University (MU), Orkestra - Basque Institute of Competitiveness (Deusto University), Public environmental management company of the Basque Government (IHOBE), and University of the Basque Country (UPV/EHU). It should be noted that for this first regional workshop, no specific companies attended. Instead, strategic clusters, policy makers and decision makers from diverse organisations, governmental agencies, and academia participated in the discussion. The objective being to contextualise the sector as a whole and to share and discuss insights from a holistic point of view.

Table 9. Participants to the first Basque country workshop.

Stakeholder	Nº attendees	Field	Description
Basque Centre for Climate Change (BC3)	1	Academia	Research centre focused on environmental economics
Basque Energy Cluster (ACE)	1	Sectoral cluster	Cluster gathering energy-related enterprises
Basque Environment Cluster (ACLIMA)	1	Sectoral cluster	Cluster focusing on the value chains of waste, contaminated soils, water cycle, air and climate change, and ecosystems
Energy Agency of the Basque Government (EVE)	1	Associated governmental agency	Governmental agency responsible for energy policy and fostering energy efficiency
Mondragón University (MU)	1	Academia	Private university
Orkestra – Basque Institute of Competitiveness (Deusto university)	1	Think-tank	Think-tank associated to a private university
Public environmental management company of the Basque Government (IHOBE)	2	Associated governmental agency	Governmental agency responsible for environmental policy
University of the Basque Country (UPV/EHU)	2	Academia	Public university

The workshop started with an introduction part providing the participants with insights about the project and working methods of the day. The Three Horizon Dialogue[26] was organised in three working sessions in which the participants worked first in two separate groups, each group involving five participants, and then the group discussions were summarised in a plenary part organised at the end of each working session. The first session was focused on debating about the present of the Basque industry, the second on its future, and the third one on how to achieve such future. The workshop was finalised with presenting the next steps. The whole event had a 4h duration and was held in English (for the introduction part by the project and WP2 leaders) and Spanish (for the stakeholder discussion).

B.3.2 Modelling background of the stakeholders

The nature of the attendees to the first Basque country workshop was diverse and their background in modelling heterogenous. Although all recognised its potentialities, the modelling capacities of each stakeholder differed. Participants from academia were familiar with modelling tools, although their kind of tools was specific to their research field: building energy modelling (UPV/EHU), circular economy (MU), and macroeconomic modelling (BC3). Sectoral clusters had participated in projects involving modelling, though they didn't have modelling capabilities on their own. Regarding governmental agencies, they had specific knowledge and capacities in terms of modelling: the environmental agency had developed carbon footprint

[26] Sharpe, B., Hodgson, A., Leicester, G., Lyon, A., & Fazey, I. (2016). Three horizons: A pathways practice for transformation. Ecology and Society, 21(2). https://doi.org/10.5751/ES-08388-210247

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calculators and GIS-based models and tools to address climate change impacts (both mitigation and adaptation), while the energy agency had experience in energy system modelling.

B.4 Case Study Results

B.4.1 Where are we now?

The Basque industry faces multiple challenges in its journey towards decarbonisation. The region's industrial landscape is characterised by influential industrial clusters and a strong tradition of regional government support. The industry is globally competitive and well-connected to international value chains. This is both an important asset and a liability, given the industry's exposure to external economic and geopolitical risks.

The industrial decarbonisation is an on-going process, and the Basque industrial companies are evaluating different solutions to transform towards more competitive and green technologies such as electrification, fuel changes, efficiency increases, and hydrogen. Overall, it is considered that technologies to decarbonise the industry are largely available, but financing is sometimes a bottleneck. Some workshop participants considered that Basque industry is highly adaptive to new technologies and has a historical trajectory of successful transitions, whereas others thought that the industry shows resistance to change, especially the SMEs, who need support in the transition. It was also considered that industrial companies are rather focused on short-term profits and survival than longer-term sustainability, whereas others considered that companies are always seeking longer term competitiveness and make investment strategies accordingly.

Although Basque industry is advancing in decarbonisation, it is facing limitations due to the energy infrastructure. The dependency on fossil fuels is still high and power grid expansion is becoming an important barrier to electrification. Another concern is related to carbon footprint and scope 3 emissions resulting from the industry being linked to international value chains. Lack of carbon capture and storage infrastructure in the region is seen also as a limitation.

In respect to circularity, there is a need to foster secondary markets of materials/waste in the region. The participants also raised the concern of critical raw materials and dependencies to economies outside the EU. Overall, it is considered that circularity levels of the Basque industry are rather low and there are unexploited synergies among different industry sectors, and even with other parts of economy, such as residential sector, that should be further explored.

Sustainability is seen as a transversal, umbrella concept covering environmental, social, and economic aspects. The participants ask for building a holistic, aggregated vision to evaluate the impacts of industrial transition altogether.

Public policy is seen as a facilitator of the transition of industry by creating "enabling frameworks". However, public policy should guide the transition in technology neutral manner and consider the impacts of the policy beyond profitability of industry including social aspects of the transition.

B.4.2 Where do we want to go?

The attendees agreed on the vision of a carbon neutral, more circular and sustainable Basque industry in the long-term horizon. Indeed, in this future view industrial processes are largely electrified (based on renewable energy sources), including a significant portion of the thermal demand. In some specific high-temperature industrial processes, green hydrogen (alongside other alternative fuels like methanol and ammonia) is emerging as a potential solution, albeit its role in the energy mix still subject to debate. The role of hydrogen is also seen limited in the longer run unless there is a significant improvement in terms of price competitiveness. The participants noted a challenge with CO_2 emissions from material processing, with carbon capture and storage (CCS) being identified as a viable decarbonisation strategy for certain industries, although not perceived as a general solution for the whole sector.

The Basque industry is well integrated with other actors of its environment through urban-industrial symbiosis and a greater vision of its responsibility for its impacts. It is also fully adopting eco-design principles, leveraging life cycle assessment (LCA), to enhance product longevity and material reuse, signalling a shift towards sustainable business models and remanufacturing. The Critical Raw Materials (CRM) are an important aspect, needing strategic actions at the EU-level. In the future, the industry will have zero or almost zero waste, with selective waste collection and new recycling technologies playing pivotal roles in waste management. Also, sustainable water consumption of industry is noted as a factor, targeting towards water conservation. The future industrial ecosystem is envisioned to be more interconnected: with residential and transport sector locally but also to global industrial value chains.

The transition to a 100% decarbonised industry by 2050 is seen as possible, but the process to achieve it will be difficult requiring a deep transformation across various sectors. It is noted that the transition will take different paths and paces depending on the industrial sector. Disruptive technologies, new actors and totally new industrial ecosystems will appear, needing also new or improved infrastructures. Novel technologies such as new materials, digitalisation, thermal storage based on molten salts, or evolution of carbon capture, storage, and use, as well as improvements in distributed energy systems and energy self-consumption can change the future pathways significantly. It is also noted that the transition will have societal implications e.g., in industrial employment. This is why the goal should be achieving a positive net sustainability impact considering environmental, social, and economic aspects all together. The role of public policy is seen as important. Regulation and investment subsidies are needed, especially in the period of transition, with high uncertainties regarding the reach of benefits to be made from investments.

B.4.3 How do we get there?

The workshop participants had a common understanding that the industrial transition requires coordinated and collaborative action involving both public and private actors. It was discussed how the real challenge of the industrial transition lies on how to conduct it without losing competitiveness of the Basque industry.

Public policy is seen as a key to foster investments and favourable framework conditions for both existing industries and potential new entrants. Long-term vision and policy commitment combined with regulatory stability, flexible and reflexive strategies incorporating learnings from reality are seen as important drivers of the transition. Subsidies and investment support addressing financing challenges are also seen as critical factors for successful transition policy. It is necessary to establish economic signals and incentives, for example in the form of green taxes based on impacts of business activities, and public-private schemes of “green purchasing” to enable the transition. SMEs are considered to need specific attention and support tools from public policy. Finally, cutting administrative burdens (red tape), and improving licensing and permissions procedures are important for making the transition processes smoother.

Technological advances and improvements are pivotal for the progress. The grid infrastructure planning and deployment of more power grids is a significant challenge that must be addressed to enable industrial transformation. Technological innovation, including e.g., the development of electrolysers, energy storage systems, heat pumps, carbon capture, storage and use, and new materials, is essential. Advancing digitalisation across the industry and enhancing the understanding of value chains and logistics are also considered important elements facilitating the transition. Material availability poses a strategic concern, needing geopolitical considerations. Research and development efforts related to new materials remains a key area of focus to support these initiatives, in addition to reinforcement secondary markets of key materials.

From the perspective of society, it should be assimilated that the transition comes with a cost, and it is reflected in the pricing of goods and services. Also, the participants raised topics related to limits of economic growth, change of consuming habits and concept of "sufficiency" referring to reasonable level and rational use of resources.

To adequately support the industrial transition, assessment and monitoring is needed at the regional level. In the planning phase, ex-ante prospective assessments are important to discuss on economic, social, or environmental performance of the different pathways. In this respect, example cases from other regions are important. The life cycle approaches should be incorporated in the analysis, and there is a need for better indicators measuring sustainability in quantifiable manner. Data availability and quality pose another challenge. From regional perspective, the data is often too aggregated, which complicates its applicability and use in modelling. There is a need for more robust and granular models requiring detailed data from different industries, markets, and scales. Although more and more data are available through digitalisation, it is often strategic and proprietary for the companies. If companies give data to the public sector or research projects like TRANSIENCE, they should receive something in return, e.g., analytical insights useful for their business.

B.4.4 Overview of key challenges, drivers and barriers identified in the Basque Country

Table 10. Overview of key challenges, drivers and barriers identified in the Basque Country

Key word	Challenges	Drivers (+) /Barriers (-)	Type*	Dimension**
Uncertainty / System	Decarbonisation of industry depends to a large extent on **changes at structural level** (energy system level) and the crucial challenge is **maintaining competitiveness while tackling the green transition**: More knowledge is needed on strategies to extend life cycles and use renewable and sustainable materials. There is a need for **building systemic approaches** to industry including both social and environmental concerns	Reluctance to change in society, administration, and companies (-); Relatively low renewable energy potential in the Basque Country (-); Obtaining financing for investments (-); Great knowledge and experience of Basque industry to systemic transformations (+); New business opportunities and creation of new industrial sectors to solve the technological challenges related to energy transition (+); Integrated vision and strategic sovereignty (+)	P / E / C	D / S
Regulation	**Maintaining EU ambition** and commitment for the **long term** and at different scales is a challenge. Thus, there is a need for **stable** regulatory frameworks oriented to green transition. Associated to this, new forms of green taxation as well as new institutions capable of developing industrial symbioses are needed, especially to promote collaboration, democratisation in decision-making, and supporting SMEs, are required. Besides, regulation should include quantitative analysis of socioeconomic and environmental consequences of the industry transformation	Short-termism in policymaking (-); Land availability for circularity solutions (-); Subsidies policies to compete with China and the US (-); Internalisation of environmental impacts (-); Incentives and support for circular business models e.g., through taxation, green public procurement, support for investments EU policy: Net-zero Industry Act, Critical Raw Materials Act (+); Eco-design: impacts need to be measured before implementation (+); Green taxation (+);Green public/private procurement (+); Financing of pilots (+); Flexibility in strategies to abandon non-successful projects (+); Carbon-neutral products backed by a digital product passport (+); Joint management for circularity governance EU planning for	P / C / E / S	D / C / S

Key word	Challenges	Drivers (+) /Barriers (-)	Type*	Dimension**
		critical raw materials (+); Developed regulation for companies (+)		
Business Case	Need for **business cases** for green products	Lack of experience with new products/services based on decarbonisation (e.g. flexibility), circularity (e.g. reutilisation), and sustainability (e.g. social fairness in manufacturing) (-); New business models based on circularity (+); Eco-designed products and processes with minimum impact (+); Pollutant-free products (+); Increase of servitisation, reuse and remanufacturing (+)	E	CE
Energy/ Electricity	Achieve an industry based on **100% renewable** energy, energy efficiency, and **electrified** wherever possible	High energy prices (-); Technology development in key technologies: green H2 electrolysers, electrical storage, heat storage, heat pumps, CO2 capture and storage, digitalisation (+)	E / T	D
Infrastructure	**Expansion**/update of electricity infrastructure capacity	Investments in infrastructure are too expensive and often dependent on national decision-making (-); Public-private coordination to allow viability of solutions (+)	T / N	D
Economy	Promotion/transition to a **high value-added industry** with high quality employment and retention of industries while attracting new ones. Besides, due to the importance of SMEs in economy, these should be supported in the green transformation to avoid excessive burdens, access to funding, etc.	Increase in the price of products (-); Future of CO2 pricing (new EU ETS) (-);Need for a clear idea of the CO2 price trajectory so that companies can make informed investment decisions (-); Long-term planning of infrastructure (e.g., grid) (+); Regional consumption drives industrial performance (+); alignment of incentives with burdens/obligations (+)	E	D / CE / S
Bureaucracy	Better and **more agile** regulations and incentives that allow and support decarbonisation and circularity	Lack of needed administrative and authorisation procedures (-); Public sector capacity is generally high (+);	C / P	D / CE
Limited funding capacity	Green production processes require massive **investments** in terms of **new plants and new infrastructure**	Limited funding for projects (-); More support to SMEs is needed (-); Subsidies for green transformation (+)	E	D / CE
Skilled workers	Need for **skilled workers**	Lack of skilled workers in circularity (-); Basque industry has powerful connections with academia (University, R&D centres...) (+)	C	D / CE
Acceptance & Public Perception	**Raising awareness and knowledge** of decarbonisation, circularity, and sustainability in industry.	Frequently, circularity is not a real concern for industry, unless it is forced upon it (-); Social acceptance of waste recycling infrastructures (-); Lack of disaggregated data and nature of data (-); Society's ability to absorb price increases (-); Low data availability and traceability (-); Industries perception: What should companies receive in return for provision of data for research/policy use? (-); Importance of critical materials is not included in depth in decision-making (-); Lack of tools for measuring social/societal impacts (-); Lack of knowledge of sustainability (-); Social acceptance of some solutions (-); Basque industry has background in eco-design (+); Potential circularity projects are already identified (+); Include circularity as driver in industrial strategies (+); Sustainability culture is integrated in companies and environment is considered in decision-making (e.g., eco-design, waste valorisation, impact awareness) (+); Technological and environmental foresight exercises (+); Development of knowledge and capacities in life cycle cost thinking and decarbonisation (+); Establishment of responsible/reasonable consumption	C / S	D / CE / S

Key word	Challenges	Drivers (+) /Barriers (-)	Type*	Dimension**
		thresholds and concept of sufficiency (+); Awareness among citizens about circularity and remanufactured/reconditioned products (+); Training of companies in circular business models (+)		
Resilience	Need for **diversified and resilient value chains**	Exposure to market risks due to dependency of specific value chains (-); Basque industrial companies have experience in innovation, and they are leading decarbonisation (+)	E / N	D / CE
Clustering and regional integration	Creation of necessary **networks and collaborations**: harmonising regional industrial and urban areas by promoting synergies between them, and establishing connection among industries for energy and CO_2 valorisation, is a real challenge	Interdependencies could act as a barrier for individual transformation efforts (-); Lack of information and visibility of circularity models and synergies between industrial sectors (-); Criticality of some material requires strategising (-); Collaborative culture (+); Existence of relevant value chains and industrial sectors in the region (+); Basque Country is a tiny region with a lot of industries, what favours the interlinking among sectors (+); If well-structured, interdependencies may serve as strong regional competitive advantage (+); Establish public-private symbiosis (+); Local symbiosis between urban and industrial areas (+)	E / C / N	D / CE / S
Recycled Materials	Creation of **secondary markets** to make circular processes sustainable, increase **recycling rates** and **improve infrastructure**	Well-functioning secondary markets in key materials (e.g., copper) (-); Limits of circularity: economic and environmental viability (-); New business models (+)	P/E	CE / S
Technology	Concerning technology by itself there are several challenges identified: - New solutions for grid expansion (**flexibility**) - **Electrification of thermal** demand and waste heat utilisation - Role and real potential of **CCS/U** and synergy with green H2 production to **create e-fuels** - Promotion of **distributed generation** - Role of thermal and electrical **storage** - **Hard-to-abate processes** and sectors (role of biofuels and H2) - Abatement of industrial **process emissions** (e.g. cement) - New technologies for **material recycling** (waste valorisation, critical materials...) - Development of **new sustainable materials** The challenge is vast: reduction of technological and material dependence and keeping competitiveness while addressing the green transition	Power grid expansion is needed (-); No infrastructure for CCS (-); Renewables intermittency: to be tackled with flexibility solutions and adapting industrial production/demand (-); Lack of analyses of the evolution of energy consumption (natural gas, electricity, H2) and costs by sectors, companies, processes (-); Material availability (-); Waste treatment: technology is not available or existing regulation does not permit to act (-); Use of energy and materials is not too digitalised, optimised and flexible as desired (-); Decarbonisation technologies are mostly available (+); Reach a 100% renewable, efficient, smart, and electrified energy system (+); Carbon-neutral energy system by 2045 (+); Eco-design based on LCA: focus on closing both materials and products life cycle loops (+) Further innovation in technologies and processes (+); Technological development and improvement/diversification of supply chains (+);	T	D / CE

* Types: Political (P), Economical (E), Technological (T), Capacity/Awareness (C), Network (N), Social (S)
** Dimension: Decarbonisation (D), Circular Economy (CE), Sustainability (S)

B.4.5 Cross-sectoral relations, trade-offs and feedbacks

Although no specific sectors were present in the workshop and therefore no industrial cross-sectoral relations could be identified, other type of linkages arose from the discussion. First, the need for electrifying certain industrial processes will require the expansion of the power grid. In turn, the development and decarbonisation of the electric network will increase the demand of resources and CRM embedded in transport infrastructure, renewable technologies, and batteries amongst others. Circularity measures are therefore needed to reduce the impact of this rebound effect emerged from the need of decarbonising industrial energy supply.

Another identified rebound effect was the one concerning the rise of energy use derived from the increase of recycling capacities. Indeed, issued from the need of reduce material consumption, recycling is to be promoted. However, new technologies for material recuperation and recycling may require additional energy demand to be covered. To ensure that the reduction of environmental impact achieved by materials savings is not offset by an increase in emissions related to energy use, this additional energy demand should be covered by renewable sources.

On the matter of circular economy, given the Basque industry dependency on external markets (both energy and materials) and the geopolitical impact on the formers, the Basque industry needs to foster circularity as a driver of its own change. Circular measures however are not always met with the acceptance of society and private companies either due to low awareness or to the lack of related legislation. To reverse this situation, a bidirectional relation should be established between policy-makers and the rest of society seeking the promotion of a co-created policy framework that will facilitate the deployment of circular economy policies considering all agents involved in the transition, supporting those affected by it, managing the potential intermediate negative impacts of the transition on the employment and the economy, and not letting the burden and impact of change fall on the less advantaged (e.g. SMEs, low income households, etc.). That is, both costs and benefits of the transition should be socialised.

A relation between public and private sectors is therefore a pivotal linkage to foster industrial transformation. Cooperation and coordination amongst private companies and public bodies is required to establish the framework (regulatory, financial, fiscal) for the transformation of the region industry. To avoid regulatory barriers that may slow-down the implementation of technological and circular measures, a strong and stable legislation is required. Along this, public support in the form of incentives and funding to assist companies, and especially SMEs, is needed to foster a fair transition to a high value industry.

Finally, from a general perspective of cross-sectoral relations, synergies amongst sectors, both in terms of decarbonisation and circularity solutions, were identified as key enablers to achieve industrial transition within the region. On the one hand, symbiosis between industrial sectors themselves, as well as interlinkages between industrial and urban areas, may enable the integration of diverse energy vectors and technological solutions, promoting the penetration of alternative fuels (e.g. H_2, ammonia, methanol, biofuels, e-fuels), technologies (e.g. CCS/U, thermal and electric storage) and business models (e.g. CCS/U for e-fuels production, H_2 as storage solution or for e-fuels production) aiming for industrial decarbonisation. On the other hand, recycling and material reuse across sectors may foster the establishment of secondary markets and the use of reconditioned products and materials, reducing resources and CRMs requirements. All in all, the creation of networks between sectors, where flows of energy vectors and materials can be integrated, shared, and reused, represents a cross-sectoral opportunity to reduce industry environmental impact and to develop innovative business models.

B.5 Synthesis I: Uncertainties and knowledge gaps

From the discussion with the industrial stakeholders, the following gaps, and requirements that modelling in TRANSIENCE could cover were identified.

In the first place, supply infrastructures (taking into account both transport and storage) should be considered. Indeed, given the expected expansion of the grid required, infrastructure planning is crucial. Moreover, mechanisms to manage intermittency from RES should be integrated.

In terms of environmental impact, stakeholders advocated for a coherent and accurate quantification and allocation of responsibilities amongst companies, government, individuals, suggesting the integration of LCA in models to assess scope 3 emissions and the impact of CRM requirements. They also remarked the need of including CO_2 emissions from processes to later evaluate the real potential and impact of CCS/U solutions.

Stakeholders attached great importance to the consideration of social aspects in models. Their proposals revolved around assessing the impact of social acceptance regarding decarbonisation and circularity projects in industries and society or evaluating social awareness when looking at reconditioned products. The concept of sufficiency, to be defined jointly, was also introduced, and was suggested to be accounted in the models. Some stakeholders pleaded for leaving behind the use of traditional drivers (such as GDP, population, energy prices, or technology costs) to model energy systems, in favour of other approaches based on behavioural components and societal aspects. They further added that qualitative aspects like social issues, health concerns, and other externalities should be considered in the modelling.

Regarding economic aspects, some stakeholders noted that Small and Medium-sized Enterprises (SMEs) should be better considered in models. In addition, an assessment of how the industrial transition would affect them should be carried out. All the attendees agreed on the need of green taxation and on the importance to reflect that its revenues should compensate issues derived from industrial transformation. Concerning scenario conceptualisation, they also asked for a discussion in depth of CO_2 prices evolution within the models to support companies in their decision-making processes.

Finally, stakeholders pointed the temporal gap between legislation drafting and its application and suggested that models should take this into account. Moreover, they raised the question on how to model symbioses between public and private entities, and between society and companies. Indeed, the modelling of interconnected flows and networks of energy vectors and resources across sectors would be helpful to assess the potential of both the integration of energy technologies and the reuse and recycling of materials. On this concern, stakeholders noted the potential value of GIS tools for the identification of resources and synergies amongst industries and other sectors.

Although all stakeholders recognised the potential and relevance of modelling as a powerful tool for prospective assessment and design of industrial transition strategies, their interests differed regarding MIC3 development. While academia saw a great potential in advancing open-source modelling, sectoral clusters asked for specific issues from companies to be solved, seeing models' outcomes as something relevant for governments. Indeed, governmental agencies saw potential in this kind of initiatives, expecting useful ad-hoc analyses to solve their own issues, though they were reluctant to participate actively. In addition, more and better data is needed. Currently available data is typically too aggregated to obtain fine-tuned and detailed results. Accurate, granular, and specific data is required to obtain useful insights for the industry. On this concern, companies could be asked to provide inputs to the model in the form of data, provided that they get back in exchange helpful results for them. Otherwise, they will be reluctant to cooperate.

B.6 Synthesis II: Key transformation challenges in the region

B.6.1 Key transformation challenges

Drawing from the workshop results, one of the main barriers for transformation of Basque industry is the limitations given by the energy infrastructure. Now, the industry has high dependency on fossil fuels, and there is low renewable energy potential available locally in the Basque region, leading to competitive disadvantage e.g., from the perspective of location of new industrial investments. The capacity limitations of power grid infrastructure are limiting further electrification of the energy system, which is an important factor embedding the transition. This is further complicated by the intermittent nature of renewable energy requiring flexibility solutions and adapting industrial production and energy demand. From the perspective of technology, limited advances of key technologies, such as electrical energy storage or green hydrogen, are further complicating the energy infrastructure limitations and thus altogether pacing down the transition.

Basque industry is very embedded in global value chains, which is an important competitive strength but also exposes the industry with external threats such as economic shocks, geopolitics, and potential disruptions in supply chains. The industry is also very much depending on global sourcing of many (critical) raw materials, which in current global geopolitical context is considered as a barrier, alongside with currently low levels of circularity, underdeveloped secondary markets for key materials and lack of infrastructure for circular economy in the region.

The industrial transformation is also slowed down by the direct and indirect costs associated to the transition. On the one hand, the industry is concerned about sources of finance for the investments needed for the transition, and on the other about maintaining competitiveness during and after the transition. The transition costs are reflected in the prices of goods and services, which in turn is seen as a risk, not only from the economical perspective but also generating larger public opposition towards sustainability transition. The burdens and benefits of the transition are also expected to be unevenly shared by different stakeholders, hindering the advancement of the transition.

One of the key barriers for the transition is the reluctancy or resistance towards change. The resistance towards change is affecting not only the industrial actors but also society at large. This is considered to be a barrier especially for advancing circularity and uptake of circular business models by industry, and acceptance of circularity and remanufactured/reconditioned products by consumers.

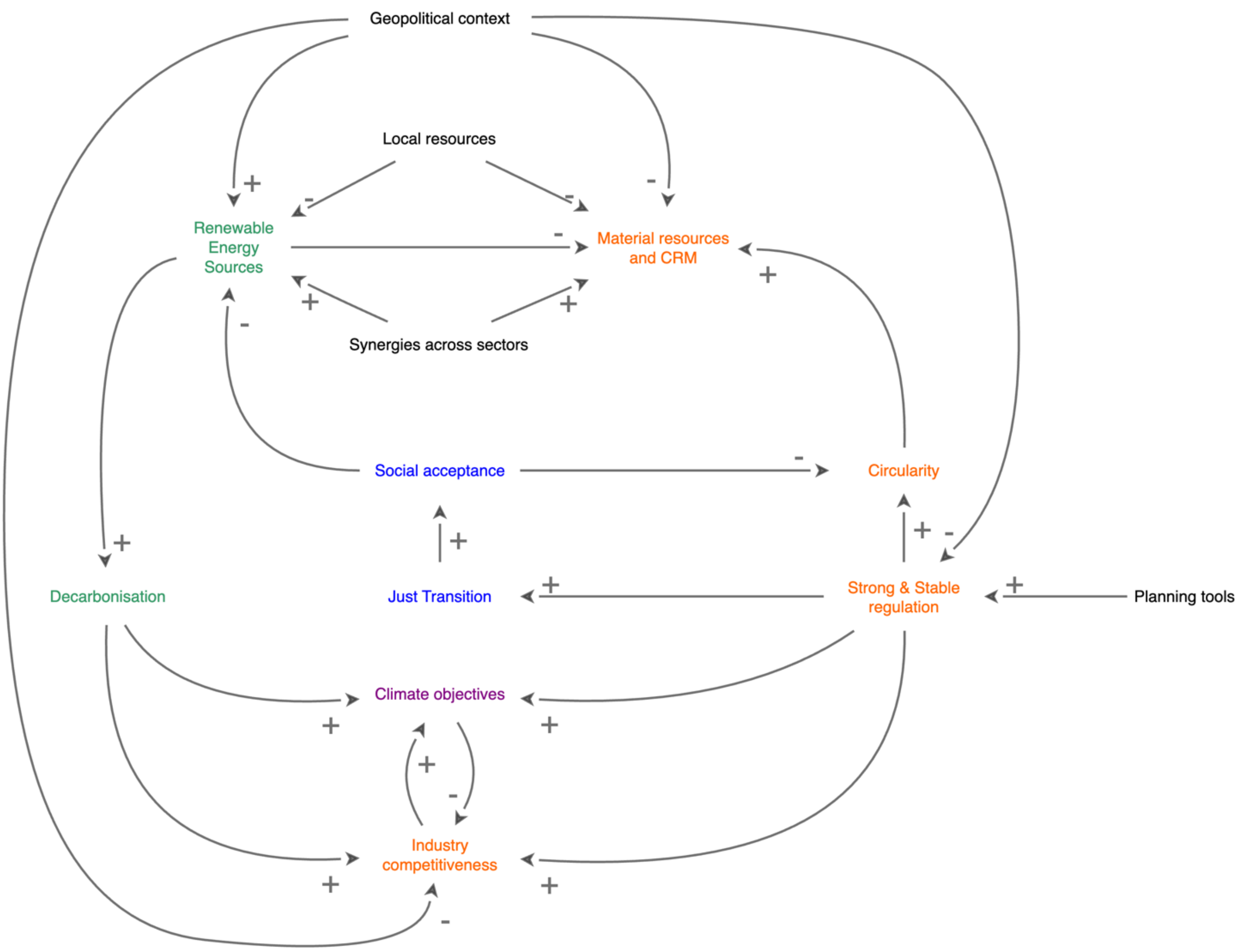

Figure 23. Causal Map synthesising key interdependencies in the transformation of industry in the Basque Country.

B.6.2 (Policy) recommendations to alleviate transformation challenges

Recommendations to advance decarbonisation, circularity and sustainability of Basque industry include establishing a long-term, stable, and coherent policy framework in different governance levels (local, regional, national, EU) to facilitate and foster the transition. The policy framework should enable transparent, just, and fair distribution of burdens and benefits of the transition among different actors of the ecosystem. This would include regulatory framework supporting the transition, incentive, subsidy, and investment support measures for industrial transformation, especially considering the needs of SMEs, and alleviation of administrative burden and permission and licensing procedures. Taxation is also key on this aspect and should serve to balance the burdens of transformation and compensate potential drawbacks. Apart from supporting industry, the public policy is expected to play an important role in facilitating public-private collaboration e.g. related to infrastructure investments, and cross-industry collaboration allowing better leverage of industrial and industry-residential sector symbiosis in local level. Moreover, public administrations can play a key role as leaders on the adoption of circularity approaches through public procurement as part of demand-side innovation policies.

In terms of research and technology, advances in key technologies such as green hydrogen, energy storage, CCS, digital or material technologies would pave the way and accelerate the transition. The R&D policy should on one hand set the long-term vision and strategic guidelines for the industrial transformation but on the other hand remain technology neutral and allow the most competitive solutions to win. To this end, rigorous integrated assessments should be carried out to support decision-making. Public-private collaboration and agreement is considered of special relevance in respect to long-term large infrastructure investments.

The workshop participants agreed that power grid expansion would be an important requisition for the further electrification of the industry. Also, further advancement of digitalisation of industry and understanding of supply chains and logistics are essentially enabling the transformation. Fostering secondary markets of key materials at local level and establishing a new entity for coordinating the use of secondary materials in the region is considered relevant. Systemic approaches for public funding schemes are needed to support the set-up of regional closed-loops, industrial symbiosis approaches and complex value networks. Depending on the technological advances of e.g., green hydrogen or other technology options, in future infrastructure investments can become necessity for decarbonising hard-to-electrify industry sectors.

From the perspective of society, further work for awareness raising related to decarbonisation, circularity and sustainability among citizens is needed. Changes in consumer habits and behaviour are important, especially for circularity. In this sense, consumers should be informed on the environmental impact and circularity of the products so that evidence-based decisions are taken by citizens. Public authorities are determinant to raise societal awareness towards sustainable lifestyles. This could be addressed through information campaigns on intergenerational climate debt, embedding circularity and sustainability awareness in educational curricula or launching programmes to inform society on the benefits of transitioning towards a greener economy. Also, discussions related to "sufficient" or rational use resources or even degrowth should be initiated at societal level to enable the transformation.

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Annex C: Silesia Regional Case Study

Arkadiusz Kocaj, Agnieska Zięcina, and Patryk Białas

C.1 Introduction

Aiming for co-creative, transdisciplinary and participatory modelling science, the development of the MIC3 integrated modelling framework within TRANSIENCE entails the reinforcement of stakeholders' role through the whole modelling and policy-making processes. Indeed, TRANSIENCE will work together with key stakeholders from policy, industry, society, and research in an iterative co-creation process developing a dynamic, two-way stakeholder feedback process that ensures stakeholders are actively engaged in the various stages and the modelling outcomes truly match their needs. Considering the divergence between the outputs of the state-of-the-art strictly formalised model frameworks (e.g., IAMs or CGE models) and the real-life policy and industry context in which decisions are taken, this initiative draws heavily on the active involvement of the most relevant stakeholders (including but not limited to industry actors, regional/national governments and associated governmental agencies, sectoral cluster associations, academia, and citizens), not only in terms of co-designing scenarios and identifying pertinent questions but also in co-developing the new model capabilities themselves. A fruitful dialogue with different stakeholders is a vital first step to meaningfully enriching modelling capacity in the light of modern challenges, without favouring specific approaches[27].

To this end, TRANSIENCE targets the engagement of relevant stakeholders, the co-identification of gaps, challenges, and opportunities in both modelling and real-world industry contexts towards the enhancement/creation of existing/new modelling capacities that will satisfy the requirements of the latter, and finally the co-design of scenarios and validation of the MIC3 framework.

Throughout the whole project workshops will be used for collecting insights that will enrich, and should be covered by, the modelling framework. During the different phases of the project, regional workshops will be held in the selected four major industrial clusters in Europe that are used as case studies: Basque country, Port of Rotterdam, Rhine-Ruhr, and Silesia. Parallelly, discussion roundtables will take place in Brussels to align regional results with EU policy and to share the different perspectives. Altogether, these series of workshops will seek to identify the knowledge gaps and research questions to which MIC3 can respond, to collect insights on industry real-world problems and requirements, to validate the modelling framework developments, and to demonstrate MIC3 capabilities through the development, modelling and assessment of co-created industrial transformation scenario narratives.

In the first stage of stakeholders and capacity needs identification, the dialogue amongst stakeholders has served for the identification of the main factors and elements impacting in the decarbonisation, circularity, and sustainability of the industries within each region. This report summarises the main comments, suggestions, concerns, opinions, and ideas that emerged in the discussion of the Silesia regional workshop.

[27] https://www.eera-set.eu/activities/research/publications.html#collapse-item-2

Funded by the European Union

C.2 Background

C.2.1 Description of the region

The Silesian Voivodeship is a highly urbanised region located in southern Poland. Its area covers 12,333 km², which accounts for 3.9% of the country's total area, and it has a population of approximately 4.5 million people, or 11.8% of Poland's total population. A majority of its inhabitants, 76.6%, live in cities. The Silesian Voivodeship generates a gross domestic product of 260.5 billion PLN, representing 12.3% of Poland's GVA, with 335.83 billion EUR attributed to industry and 268.32 billion EUR to trade. Despite the high level of urbanisation, the region boasts a rich biodiversity and a significant amount of forested land, which covers 32.1% of the area.

Upper Silesia, part of the Silesian Voivodeship, is the most industrialised area in Poland, with annual carbon dioxide (CO_2) emissions exceeding 33 million tons. This region has a diverse industrial activity, encompassing almost all mining and processing sectors. The mining sector is particularly strong, with 16 coal mines in operation, while the energy sector, with a capacity of about 7 GW, accounts for 20% of the country's total power capacity. In 2021, the region consumed 26,240 GWh of electricity, representing 16% of Poland's total consumption (*Statistics Poland*).

In 2022, 79,500 people worked in coal mines in Silesia, making up a significant portion of the 185,000 miners employed across the European Union. Although the region underwent an industrial transformation in the 1990s, leading to significant reductions in mining employment, socio-economic challenges from the restructuring of the sector remain, and plans to close mines continue to face social resistance (*Statistics Poland*).

Upper Silesia is home to large industrial facilities, including coal-fired power plants and heat plants, steelworks, and coke plants. The air pollution problem in the region stems not only from large-scale industry but also from so-called "low emissions" from smaller sources, such as household heating systems. While energy is mainly generated from coal and gas, the share of renewable energy sources is growing, with energy production from small renewable energy installations increasing from 176.6 GWh in 2016 to 532.1 GWh in 2021 (*Statistics Poland*).

In 2021, the gross value added (GVA) in the Silesian Voivodeship was approximately 63.6 billion EUR, reflecting a growth of 38.7% compared to 2015 (Figure 21). The industrial sector accounted for 33.2% of the GVA, indicating an increase from 2020 but a decline compared to 2015. The sectors of trade, transportation, hospitality, and information and communication contributed 26.8%, while agriculture contributed the smallest share at only 0.7% (*Statistics Office in Katowice*).

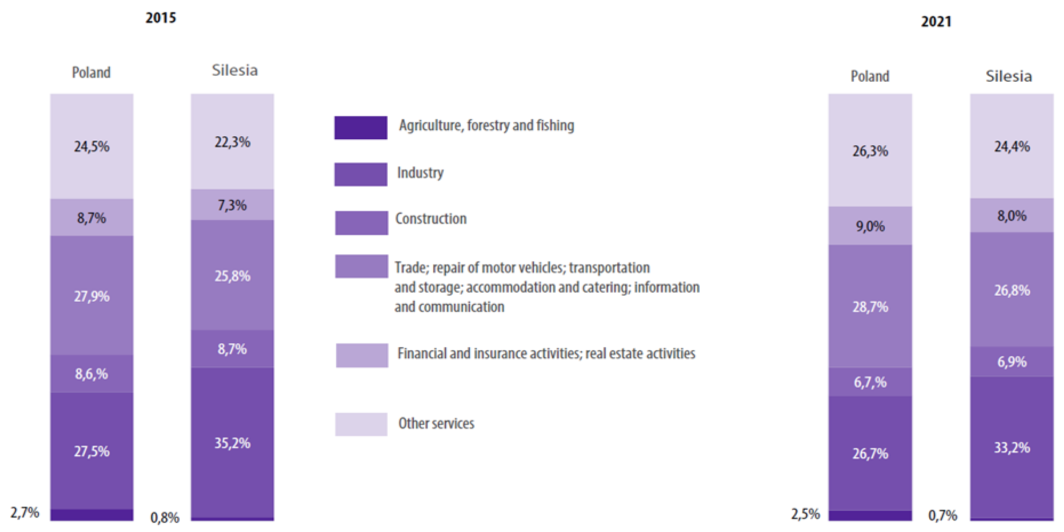

Figure 24. Gross value added by kind of activity (Statistics Office in Katowice)

As of the end of October 2023, 1.7 million people were employed in the national economy, accounting for 11.3% of the total workforce. This represented a 0.2% decrease compared to December 2022 (Figure 22). Men made up 53.1% of the workforce (approximately 904,100 individuals). The largest employment sectors were manufacturing (21.6%) and trade and vehicle repair (15.2%), while the smallest was culture and recreation (1.2%). The most significant declines in employment were seen in agriculture (down 2.5%), trade (down 2.2%), and transport (down 1.0%). Conversely, employment increased in administration (by 3.7%) and health and social care (by 1.0%) (*Statistics Office in Katowice*).

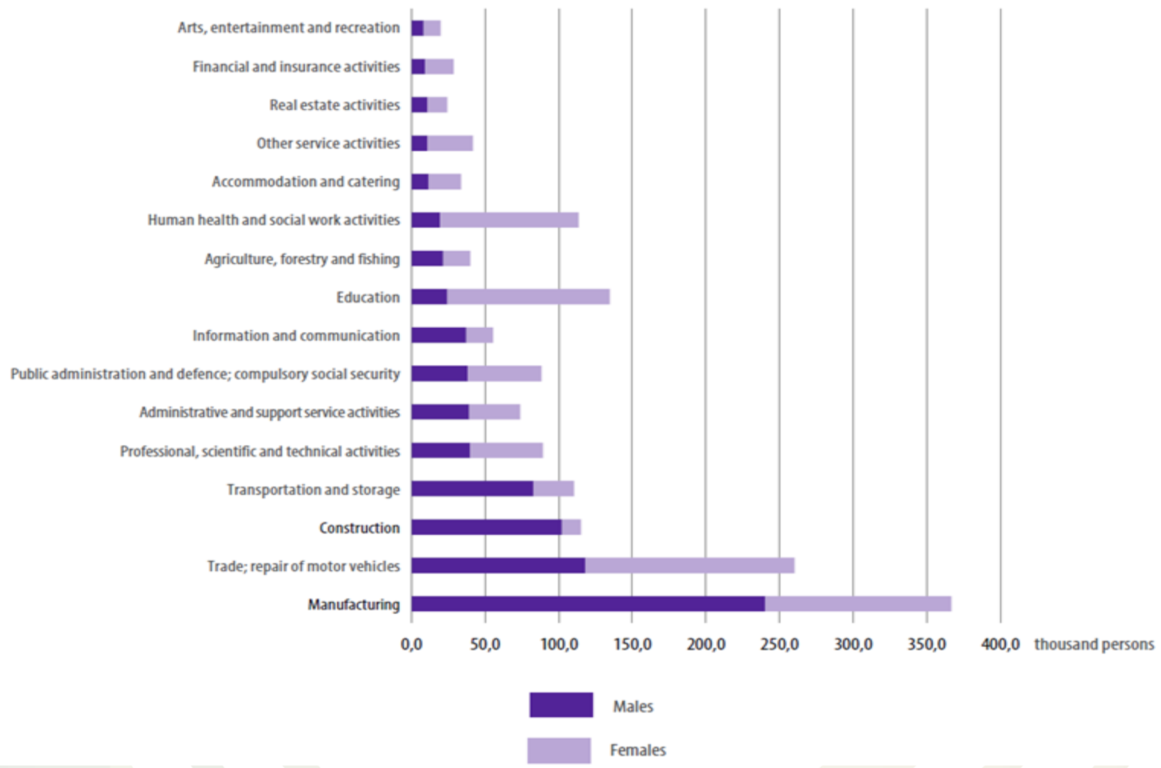

Figure 25. Employed persons in national economy by PKD/NACE sections and sex in 2023 as of 31 October (Statistics Office in Katowice)

In 2022, the installed capacity of power plants in the Silesian Voivodeship reached 8,501.5 MW, accounting for 14.1% of Poland's total installed capacity (60,422.7 MW). The achievable capacity was 8,332.5 MW (14.2% in Poland, 58,750.7 MW). Compared to 2015, installed capacity increased by 16.5% but decreased by 6.7% from 2021. In the country, installed capacity rose by 49.8%, and achievable capacity by 47.1% since 2015. In 2022, 83.1% of the achievable capacity in the region came from professional power plants, with 76.2% from thermal power plants, primarily coal-fired (74.2%) (*Statistics Office in Katowice*).

In 2022, both particulate and gaseous emissions from air-polluting facilities in the Silesian Voivodeship decreased compared to 2021 and 2015. The majority of particulate pollutants originated from fuel combustion. Carbon dioxide accounted for over 98% of total gas emissions. Air pollution control devices captured nearly 100% of particulate pollutants and almost 30% of gaseous pollutants (excluding carbon dioxide) (*Statistics Office in Katowice*).

In recent years, numerous initiatives aimed at decarbonisation and improving energy efficiency in the Silesian industry have emerged. For example, regional industrial clusters collaborate with public administration and leading energy companies to create new market opportunities based on innovative solutions. Additionally, efforts are underway in the region to transform existing industrial areas by seeking energy synergies, promoting resource efficiency, implementing technological innovations, closing mines, and retraining workers.

C.2.2 Justification of case selection

Identifying significant stakeholders for the project requires defining who the stakeholders are first. The preparation for identifying stakeholders for the Silesian regional cluster consisted of several steps. Identification of the subject from the industry sector came first. What followed after was the defining of a group of decision-makers and community organisations.

Identifying stakeholders – industrial sector

The industrial sector was assumed to provide most stakeholders for the Silesian cluster. At the same time, it was a major challenge due to several characteristics of Poland and the region. Historical conditions, including, among other things, of the creation of the region's area of the highest concentration of industrial production in Poland, overlapped with the processes of de-industrialisation and transformation of the industry in the region.

The challenge on the national and regional region was the unavailability of statistics, as well as their inconsistency or incompleteness. Based on the publicly available statistical data, stakeholder identifications began by adopting a level of analysis at the level of PKD 2007 divisions in sections of the broadly defined industry and therefore sections B, C, D and E:

- B – mining and quarrying
- C – manufacturing
- D – electricity, gas, steam, hot water and air conditioning manufacturing and supply
- E – water supply; sewerage, waste management and remediation activities

The foundation of the embraced method was to determine which industries are significant to the region. This significance was determined by constructing 16 indicators and metrics which described the share of particular sectors in the region’s industry. The availability of data conditioned the level of analysis. At the level of whole sections or divisions of the PKD, data were collected to describe the basic characteristics of the region's industry by category:

1. Quantitative description [calculated shares in the voivodeship]
   - Indicator 1 - number of entities operating during the year
   - Indicator 2 - sold production [PLN]
   - Indicator 3 - average employment
   - Indicator 4 - national economy entities inscribed in the region register
   - Indicator 5 - national economy entities deregistered to the region register
2. Industry efficiency
   - Indicator 6 - the ratio of sold production to energy consumption [PLN/TJ] – calculations for the entire country, the assumption was made that there are no significant regional differences
   - Indicator 7 - the electricity consumption per one employee [MWh]
   - Indicator 8 - energy intensity of sold production [kWh]
   - Indicator 9 - sold production/1 employee [PLN]
3. Environmental aspects [calculated shares in the voivodeship]
   - Indicator 10 - industrial sewage drained away including polluted water.
   - Indicator 11 - emission of particulate pollutants
   - Indicator 12 - emission of gaseous pollutants (SO2; CO)
   - Indicator 13 - total waste produced during the year
   - Indicator 14 - waste recovered by the producer (on its own)
   - Indicator 15 - percent of waste recovered (indicator 14 / indicator 13)
   - Indicator 16 - CO_2 emission

Statistical data for the mentioned indicators originated from the Central Statistical Office, Eurostat and statistics of the Provincial Office in Katowice, and the up-to-datedness of the data is 2022. This set is strongly dictated by the availability of data for analysis. However, it provided a basis, after a research team discussion, for selecting industries considered relevant for the Silesian cluster. Stakeholders were first identified in the following industries:

- Mining of coal and lignite
- Manufacture of food products
- Manufacture and processing of coke and refined petroleum products
- Manufacture of chemicals and chemical products
- Manufacture of rubber and plastic products
- Manufacture of other non-metallic mineral products
- Manufacture of metals
- Manufacture of fabricated metal products, except machinery and equipment
- Manufacture of electrical equipment
- Manufacture of machinery and equipment not elsewhere classified
- Manufacture of motor vehicles, trailers and semi-trailers excluding motorcycles
- Electricity, gas, steam, hot water and air conditioning manufacturing and supply

A database of companies has been built for each of the 12 selected industries. This was done using a tool in the form of a company search engine in the information and analytics EMIS platform. Silesian companies were selected in each industry and then ranged using the revenue size criterion (for the year 2022). This gave a base of 120 industrial companies. Then, the results of the automatic search were verified by members of the research team. Both the location (or in the region) and the size were evaluated. Data from company reports published in the National Court Register were used for this purpose. This laborious stage allowed the stakeholder database to be cleared. These lists were further filled with companies selected by experts from the PNT EC. Existing experience in cooperation and the results of previous projects were used for this.

In the end, a list of 90 industrial companies from the Silesian Voivodeship was created, which to the stage of stakeholder mapping.

The list of important project stakeholders also includes decision-makers, scientists and the project's social environment. Using various methods (brainstorming, reviewing press and industry portals, NGO's registers, experience of the team's members, lists of fields of study at universities), a list of companies was added to the database:

1. Six decision-makers (3 on the national level and 3 on the regional level)

2. Seven organisations and associations

3. Seven research units

The resulting potential stakeholder pool consisted of 110 people and became the basis for mapping stakeholders. According to the project's assumptions, a power – interest matrix was used to determine the degree of stakeholder involvement in the project. For better visualisation, a scale ranging from -5 to +5 was adopted.

The next step was to transfer the effects of the work done so far into an electronic version. This stage allowed visualisation of industry clusters, discussion about the results and decisions on the construction of the most involved stakeholders. In the result of these actions a final version of the matrix was created (Figure 23).

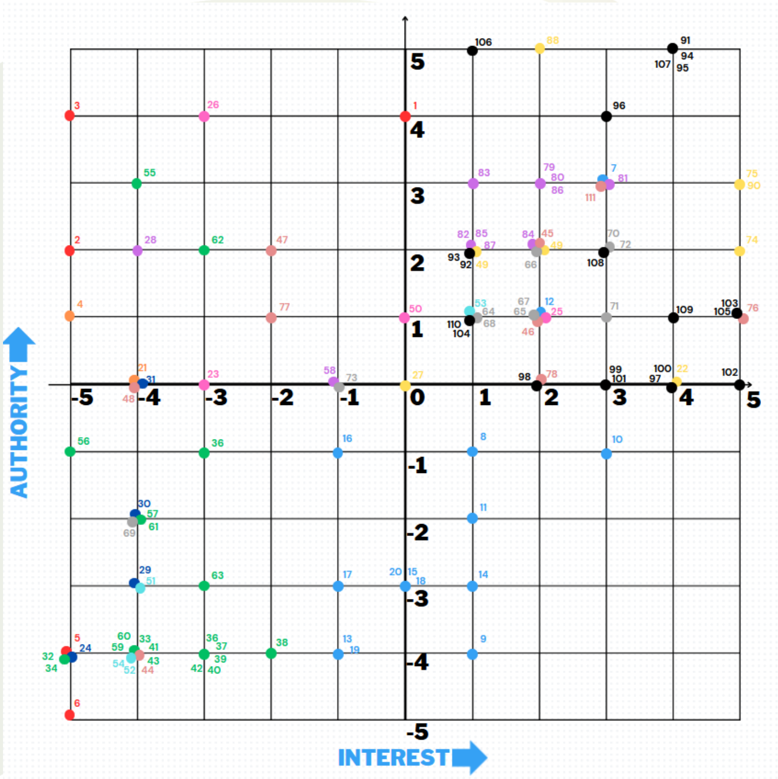

Figure 26. Power-Interest Matrix.

After the final verification of the mapping, a list of 65 stakeholders was created, who were potentially the most involved and influential group of entities in the Silesia Voivodeship. For selected companies, a contact database has been developed in accordance with the proposals from the Transience project's documents. Identification of contact persons was dictated by the size of the company or organisation; each stakeholder was invited to participate in the project through 2-3 channels.

C.2.3 Key industrial clusters in the region and their relevance

In the Silesian region, industry has historically been shaped by the presence of hard coal deposits. The numerous coal mines led to the concentration of heavy industry in the region, which required coal for its technological processes. Currently, the automotive sector is the most crucial for the region, becoming leader in value of sold production, and second-largest employer. In 2022, the value of sold production for the automotive sector exceeded 14 billion euros, accounting for 17.4% of all industrial sectors in the Silesian region (Figure 24). The largest companies in the automotive sector collaborate within the Silesia Automotive & Advanced Manufacturing cluster, which serves as a platform for knowledge exchange and cooperation between businesses, educational institutions, and research entities.

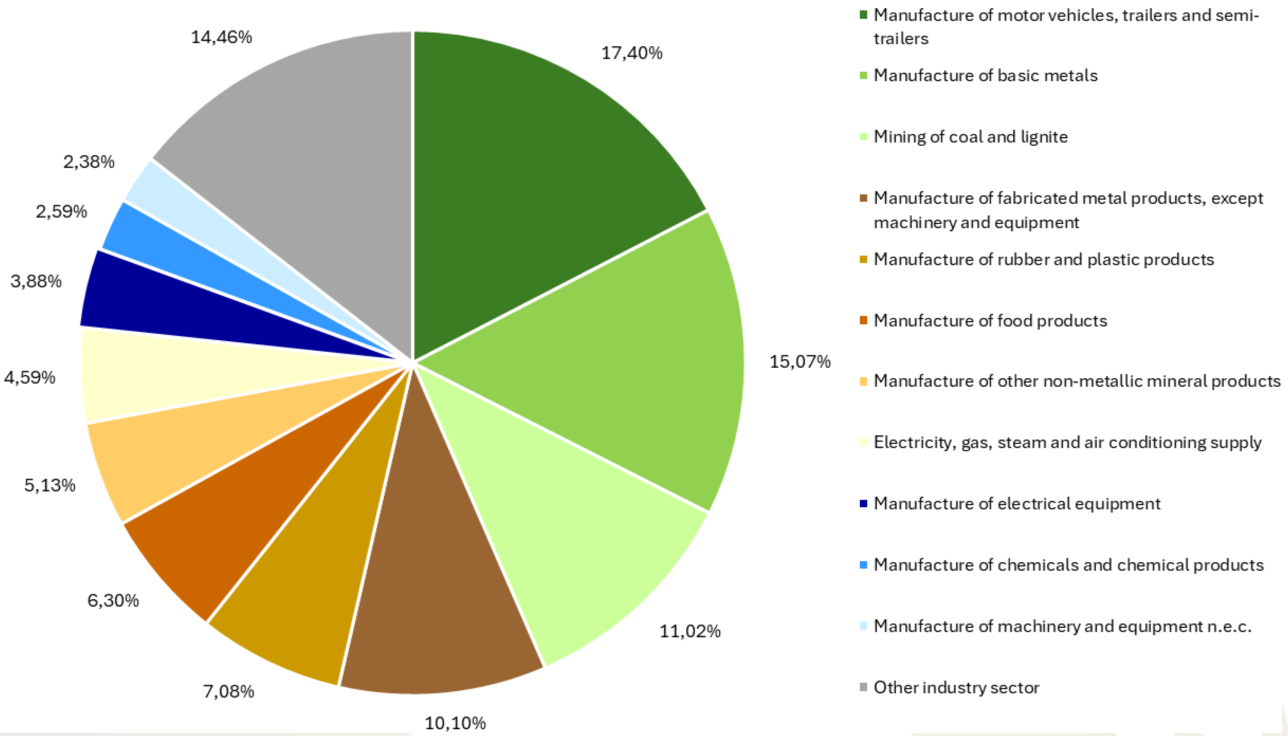

Figure 27. Value of sold production for key industrial sectors in Silesia Region for 2022 (Statistics Poland)

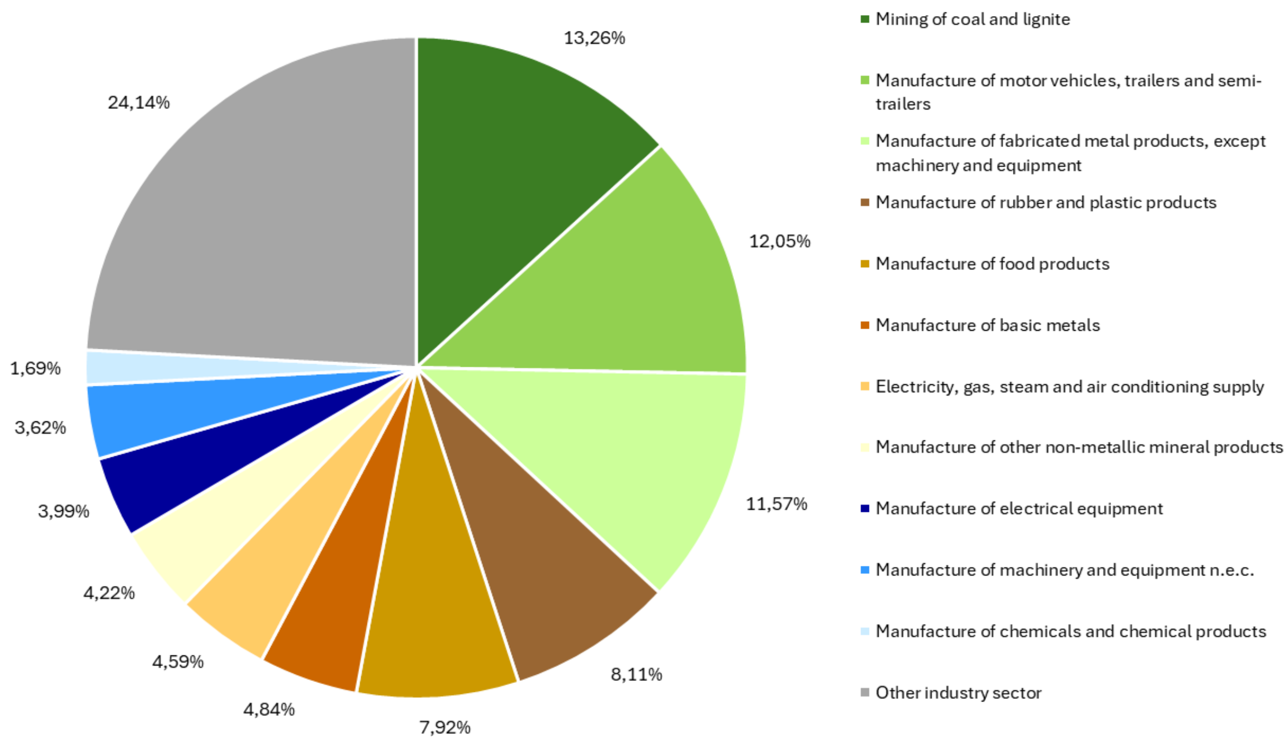

Figure 28. Share of key industrial sectors in terms of employment for 2022 (Statistics Poland).

The mining industry remains the largest employer in the region, employing 13.26% of industry employees (Figure 6). Despite being the most important employer, it only ranks 3rd in terms of value of sold production. The fair transition of this sector is currently one of the most significant challenges for the region. The Manufacture of basic metals and Manufacture of fabricated metal products (except machinery and equipment) sectors are responsible for more than 25% value of sold production in the region. These sectors are heavily dependent on the hard coal extracted in the region, which is often essential for their technological processes. These sectors are the backbone of the region's heavy industry.

C.3 Case Study Method

A core group of stakeholders (following stakeholder engagement strategy D2.1)

- 1 person from government authority – Ministry of Industry
- 2 persons from regional authority – Marshal's Office of the Silesia Region, Association of Mining Municipalities of Poland
- 2 persons from business environment institutions – Regional Chamber of Industry and Commerce in Gliwice, Silesia Automotive & Advanced Manufacturing
- 3 parsons from research organisations – Institute of Energy and Fuel Processing Technology, Central Mining Institute – National Research Institute
- 2 persons from university – University of Silesia, University of Economics in Katowice
- 1 person from private company – Grenevia

Funded by the European Union

- 2 persons from an environmental NGO – Polish Ecological Club

Invitations were sent to all 65 companies and organisations identified as relevant (Section C.2.2). Several attempts were made to contact and invite participation. This is how it was possible to get 18 workshop participants. The event was performed on 18 September 2024 from 10.00 to 13:00 in person and conducted in Polish. Participants were welcomed by the organisers and briefly introduced to the principles of work during the workshop. The participants then listened to a presentation of the project given by the project leader and the WP leader. A short introduction round followed and the 3-Horizons-Method was explained. Two sessions of 80 and 55 minutes, with coffee breaks in between. First session was about the present industry system and current challenges experienced (Horizon 1) and about future aspirations for the industry system (Horizon 3). Second session was about how to get to the future vision, about important innovations and barriers for the future system (Horizon 2). A closing session and the possibility for feedback were given and a networking lunch closed the workshop.

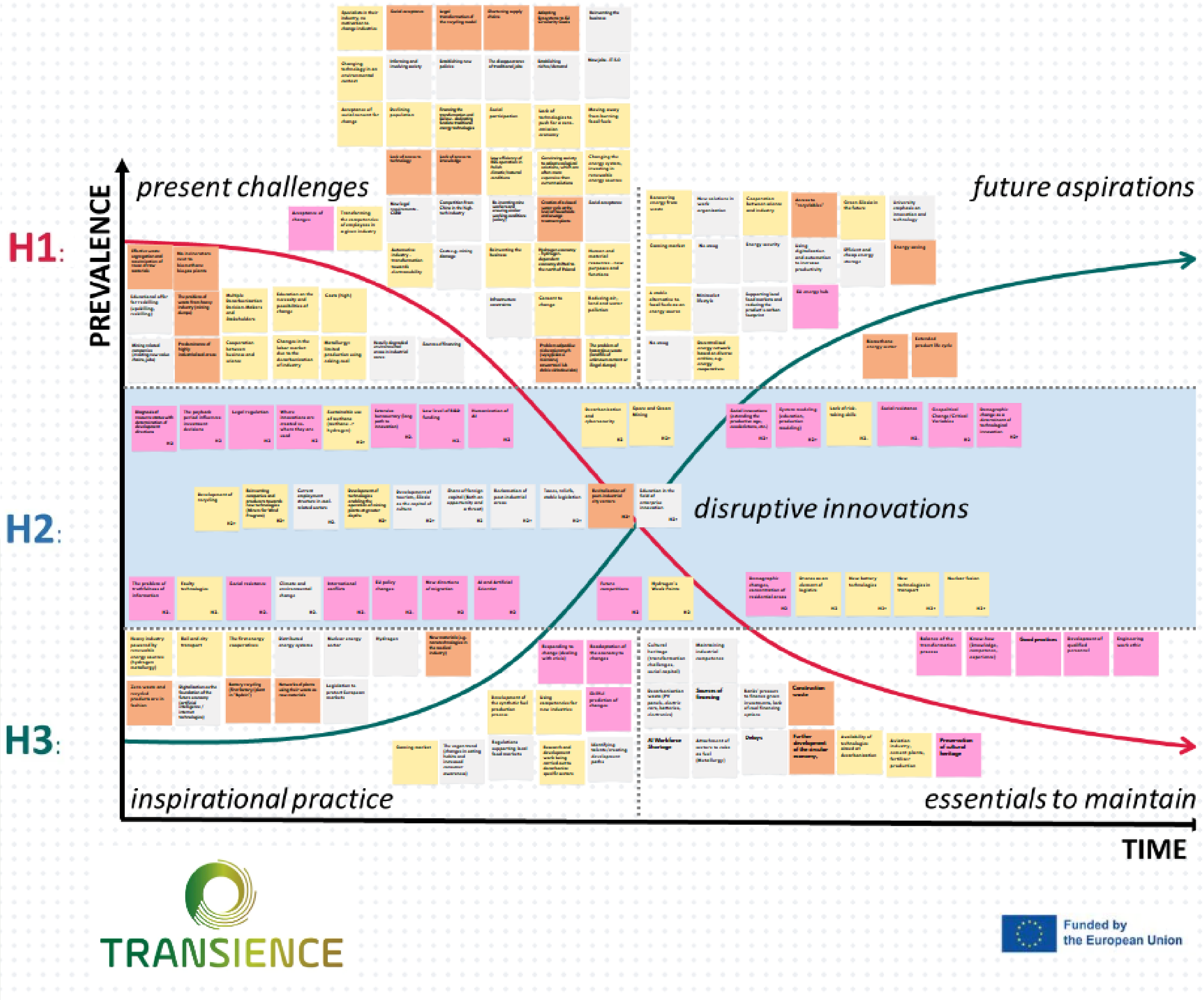

Figure 29. Completed matrix using the 3H method - the result of the regional workshop

C.3.1 Modelling background of the stakeholders

The diverse group of regional workshop participants from the Silesia region had very different modelling backgrounds. Those from academia were experienced researchers in modelling. This included modelling from the intersection of economic and sociological sciences (NPF), sociological (modelling of class positions' reproduction) and economic (models of economic regulation). Industry clusters participated in projects involving modelling, although they did not have modelling capabilities themselves. As for people from the ministry and regional authorities, they had specific knowledge and modelling knowledge, but modelling experience was not significant. Modelling was carried out by individuals representing research institutions. These included carbon footprint, decarbonisation and circular economy modelling. The institutes represented at the workshop had particular experience in modelling related to coal and natural gas. The industry representatives had knowledge and experience in both the region's traditional industries (e.g., automotive or underground mining machinery) and, at the same time, had brands in their portfolio implementing projects that fit into the energy transition (wind power, electromobility). Modelling in their business was very technological but their knowledge and experience proved very fruitful for the conclusions of the workshop. The pool of participants was complemented by people from NGOs, who represented associations working in the field of transformation of mining and environmental communities. They brought a unique perspective to the elements of the model being developed in the project based on the strong social aspect of transformation.

C.4 Case Study Results

C.4.1 Where are we now?

The Silesian region faces significant industrial challenges as it transitions towards sustainability and decarbonisation in line with EU circular economy goals. A primary issue is the need to adapt ecosystems to meet circular economy targets, which require industries to reduce waste and use resources more efficiently. Decarbonisation is particularly pressing in sectors like mining and metallurgy, where reducing the reliance on fossil fuels and coking coal is difficult due to longstanding practices and economic dependence. The automotive sector, for instance, is shifting toward electromobility, requiring significant investments in retooling production lines and developing electric vehicle supply chains. In metallurgy, there is a need to reduce reliance on coking coal, which remains deeply ingrained in the sector.

A critical technological barrier is the limited access to efficient technologies necessary for a zero-carbon transition. High costs and insufficient infrastructure make it difficult for industries to adopt new energy systems and phase out fossil fuels. Expanding the hydrogen economy could aid hard-to-decarbonise sectors, but the region lacks the necessary infrastructure for hydrogen production, storage, and distribution.

Transforming labour market is a crucial aspect of the region's transition, as traditional industries continue to decline. The reskilling and upskilling of workers are essential, especially for those in mining and metallurgy, who may lack the motivation or resources to change careers. The emergence of new sectors, such as renewable energy and advanced manufacturing, creates opportunities for job growth, but there is a significant skills gap, particularly in areas like artificial intelligence and digital technologies. Addressing this gap is vital for integrating new technologies and driving innovation.

Effective waste management is necessary to handle the diverse materials generated during decarbonisation, including photovoltaic panels, batteries, electronic waste, and mining byproducts. The region's industrial zones are heavily degraded, necessitating extensive remediation efforts. The region also faces persistent pollution problems, with heavy industry emissions affecting air quality, and contaminated sites impacting soil and water health. Investing in modern pollution control technologies and stricter environmental regulations is needed to improve overall ecological conditions.

The social dimension is also crucial, with the region facing a declining population and an aging workforce, making it harder to reskill from declining industries like mining. To maintain economic resilience, upskilling and reskilling programs must be expanded to meet the demands of new sectors such as renewable energy and digital technologies. Engaging the public in the transformation process through participatory decision-making and transparency is vital for gaining social acceptance and ensuring a just transition.

Financial and regulatory barriers are significant obstacles. The high costs of decarbonisation measures, coupled with stringent new regulatory requirements like the CSRD, place a considerable burden on companies. A coordinated approach to financing, with better alignment between EU regulations and funding mechanisms, is essential. The involvement of multiple decision-makers in the decarbonisation process creates inconsistencies, complicating the implementation of cohesive policies.

Overall, the Silesian region's path to sustainable development requires overcoming technological, financial, environmental, and social challenges through coordinated efforts that integrate industrial modernisation, workforce transformation, and better regulatory frameworks.

C.4.2 Where do we want to go?

The Silesian region is undergoing a critical transformation in response to the pressing need to transition from a coal-based energy system. Key aspirations include the integration of renewable energy sources (RES) into heavy industry, exemplified by initiatives in hydrogen metallurgy and the development of the nuclear and biomethane power sectors. Additionally, the region aims to implement efficient and low-cost energy storage solutions, establish distributed energy systems, and promote energy cooperatives. Achieving energy security remains the overarching goal, which could be partially supported by the establishment of an EU energy hub.

In the industrial and technological landscape, the region is striving to innovate through the introduction of new materials, such as nanotechnology, and efficient battery recycling processes. There is a significant push toward synthetic fuel production and the establishment of networks of plants that utilise waste as raw materials. The advancement of artificial intelligence, alongside digitisation, is expected to underpin the future economy. Industry sees a big potential in AI development. Especially with regard to cost optimisation and process improvement. One of our workshops participants pointed out a lack of labour-force in logistics and transportation. AI, and Industry 4.0 more broadly, are gaining significant importance for Silesia's industry. They were not created strictly to support the transformation but are now beginning to be more widely used in it. This is happening, for example, through strong relationships with the automotive industry. This is bolstered by strong collaborations between academia and industry, with universities emphasising innovation and technology as vital components for the development of new sectors.

Environmental challenges are central to the region’s goals, as efforts are already underway to change sustainability habits. Aiming for a "Green Silesia," the region seeks to maximise energy efficiency, enhance the life cycle of products, eliminate smog, and improve access to recyclable materials. Supporting regulations that promote local food markets and initiatives aimed at reducing the carbon footprint are critical to achieving these environmental objectives.

On the societal front, the Silesian region aspires to identify and nurture talent while creating pathways for their development. There is a growing emphasis on anticipating and adapting to changes in the labour market, alongside new organisational solutions for work and mass transportation. Legislative measures to protect the European market are also being pursued to ensure the region can navigate future economic challenges effectively.

In summary, the Silesian region's industrial landscape faces significant challenges in energy transition, technological innovation, environmental sustainability, and societal adaptation, all of which are crucial for building a resilient and modern economy.

C.4.3 How do we get there?

The Silesian region faces significant challenges and opportunities for innovation within its industrial landscape, particularly in transitioning away from coal reliance. A crucial aspect is the restructuring of employment in coal-related sectors, which can facilitate the adoption of new technologies. A regional program to re-brand miners as wind turbine service technicians was cited as an example. Innovation in mining would be fostered by the development of technologies that enable mining plants to operate at greater depths, as well as ocean and space mining could affect for the region's economic evolution.

Breakthrough technologies have the potential to drastically accelerate industrial transformation. Key areas of focus include mastering nuclear fusion, further advancing artificial intelligence (AI), and the development of artificial scientists. The development of new battery technologies and technologies in transportation would also have a great impact. The problem is flawed technologies, hydrogen weaknesses and the innovation gap.

Climate and environmental change act as significant drivers for transformation in the region. To support sustainable development, Silesia must invest in recycling initiatives and integrate new technologies into waste management processes. Developing technologies for the sustainable use of methane, including hydrogen production from methane, is vital. Moreover, the rehabilitation of brownfields and the revitalisation of post-industrial cities will positively reshape the region’s identity and promote economic growth.

Social factors also play a role in hindering innovation. Resistance to change, a lack of risk-taking culture, and demographic shifts can impede progress. However, humanising artificial intelligence and adapting the education and production systems to meet future needs can foster a culture of innovation within society.

Regulatory and financial obstacles present additional challenges to the emergence of innovations. A low level of research and development (R&D) funding, bureaucratic hurdles, and lengthy payback periods for investments can deter businesses from pursuing innovative projects. The participation of foreign capital can be a double-edged sword, offering both opportunities and risks. To encourage innovation, solutions such as tax breaks, supportive legal frameworks, and stable legislation are essential.

In summary, the Silesian region must focus on redefining its industrial identity, harnessing breakthrough technologies, addressing environmental challenges, promoting social acceptance, and creating a supportive regulatory environment to successfully navigate the transition to a more innovative and sustainable economy.

C.4.4 Overview of key challenges, drivers and barriers identified in Silesia

Table 11 Overview of key challenges, drivers and barriers identified in the Silesia Region.

Key word	Challenges	Drivers (+) /Barriers (-)	Type*	Dimension**
Space	Transformation requires consideration of a large share of brownfield sites	Possibility to use the remaining infrastructure from the previously operating industry (+) The resources accumulated on brownfields sites can be reused (+) Change may require a lot of money, sometimes these are areas that are difficult to access (-) Developed infrastructure - highly industrialised areas have well-developed infrastructure (transportation, energy), which lowers investment costs for new businesses (+) High land and rental prices (-) Market fragmentation - innovations created in one place may not be adapted to the specific needs and conditions of other markets, which limits their use and results in many innovative solutions not being applied in practice (-)	E/T	D/S
Energy /Electrification	Transformation competes with the region's conventional energy sources. Decentralised power grid based on diversified entities and distributed energy systems	The high cost of upfront investment in RES infrastructure can discourage investors and slow the pace of the energy transition (-) The need to develop energy infrastructure and charging networks, which entails large financial outlays (-) Increased energy autonomy - the emergence of the first energy cooperatives enables local communities to generate and manage their own energy (+) Difficulties in coordination and management in decentralized grids (-) Improved resilience to failures - Grid-based distributed energy systems improve resilience (+)	E/T/P	D
Policy	Despite existing policy attention, it is necessary to strongly outline directions for change, appoint coordinators and develop viable tools for implementing change Taxes, concessions, stable legislation - introducing a comprehensive system to implement and sustain circularity in the industry Changes in EU policies	Collaboration among different stakeholders can lead to innovative solutions for decarbonisation (+) Multiple decision makers allow for a greater diversity of perspectives and approaches, which can increase the effectiveness of decarbonisation efforts (+) Large investments and consequently increased costs entail the risk of losing business competitiveness (-) Multiple decision makers allow for a greater diversity of perspectives and approaches, which can increase the effectiveness of decarbonisation efforts (+) Complicated decision-making structures can slow down the pace of decarbonisation efforts (-) stability and caution in decisions - lack of risk-taking skills can lead to a more cautious and thoughtful approach in decision-making (+) Reduced innovation - lack of risk-taking skills can inhibit innovation and growth (-) Reclamation of brownfields - as an opportunity to reincorporate them into the economic cycle. Exploiting their potential while protecting or making more sustainable use of other sites (+) Extensive bureaucracy (long path to innovation) (-) Regulatory uncertainty and instability - frequent changes in EU policies can lead to uncertainty among	P/N/C	CE/S

Key word	Challenges	Drivers (+) /Barriers (-)	Type*	Dimen-sion**
		businesses, which makes long-term planning difficult and can discourage investment, fearing unfavorable regulatory conditions in the future(-)		
Ecosystem	Prevalence of heavily industrialised areas Shortening supply chains Cooperation between science and industry	Research provides companies with knowledge of new technologies and materials that can lead to more sustainable and efficient solutions (+) The long lead time for scientific research may not be in line with the fast pace of businesses, limiting the willingness to invest in research projects (-) Lack of understanding of language and processes in both business and science can lead to communication problems and ineffective collaboration (-) Proximity to suppliers and customers (+) Short supply chains can reduce costs, risks and increase resilience (+)Low level of R&D funding - Silesia, like Poland, is inferior to other industrialised regions in the level of R&D funding(-) Synergy between research and the market - the proximity of the place where innovations are created to the places where they are used (e.g. industry, cities) fosters cooperation between science and business(+)	P / E / C	D / S
Regulation	Legal transformation of the recycling model	Mandatory recycling targets for companies can stimulate the development of more sustainable production models, reducing waste and improving raw material efficiency (+) High cost of compliance with new regulations (-) Complicated regulations can introduce bureaucratic hurdles (-) Increased transparency - new regulatory reporting requirements (CSRD) promote greater financial and social transparency (+)	P/E/C	CE/S
Economy	Promotion/transition to high value-added industries while developing and attracting "green" industries Competition from China in high-tech industry Adapting to a changing market - The re-branding of companies and manufacturers toward new technologies	Increased availability of funds - Growing pressure from banks to finance green investments (+) High transition costs (-) Increased innovation - competition from China is forcing companies to constantly innovate and improve their products, leading to improved quality and productivity (+) but make difficult to keep regional products profitable and competitive (-) More accurate analysis of profitability - a clearly defined payback period (ROI) encourages investors to analyze the profitability of projects more closely, which can lead to better decision-making and the selection of more promising investments (+) New funding and support opportunities - changes in EU policies may introduce new support and funding programs for businesses, which stimulates investment in innovation, renewable technologies and sustainable development (+)	E/P/N	S/D
Labour market	Transformation requires skilled workers but cannot leave out specialists from the region's traditional industries	The possibility of using a competent and skilled workforce in new professions (+) Professionals not always show willingness to re-brand themselves (-) AI workforce deficit (-)	S/E	D
Acceptance & Public	Convincing the public to go green, often more expensive than current	Education and public campaigns promoting the health and economic benefits of green solutions can	P/C/S	D/CE

Key word	Challenges	Drivers (+) /Barriers (-)	Type*	Dimen-sion**
Perception	solutions Balance of the transformation process	increase public support (+) The higher cost of green solutions can deter consumers, especially in times of economic crisis or high inflation (-) Continued identification of garbage with waste rather than a resource affects attitudes toward segregation and availability of raw material (-) Support for sustainable initiatives (+) Increased public trust - public agreement on various projects and policies can accelerate their implementation (+) The need to obtain broad public approval can prolong decision-making and project implementation (-) Resistance to change - in many sectors, there can be resistance to change due to attachment to traditional practices (-)		
Clustering and regional integration	Multiple decarbonisation decision makers and stakeholders	Collaboration among different stakeholders can lead to innovative solutions for decarbonisation (+)	P/N	D
Technology	There are several challenges identified: • Necessary changes require many technologies that are not always present/will be present in the region • Role of H_2 and biofuels, biogas • Sectors' attachment to coke as fuel (metallurgy) • Leveraging the potential of mining companies in transformation processes • Heavy industry powered by RES (hydrogen metallurgy) • Development of the synthetic fuel production process • Battery recycling • Digitalisation as the foundation of the future economy (artificial intelligence / internet technologies) • Faulty technologies	Artificial intelligence (+), Hydrogen storage (+), biogas (+), nuclear power (+), nanotechnology (+), synthetic fuels (+), Slower interest in the electric car market than expected (-) The regional industry is firmly rooted in traditional value chains (i.e., for the production of combustion cars) (-) High availability of organic waste, which will allow for its use in heat and power generation processes (+) Tradition and experience - the long-standing use of coke in metallurgy ensures established infrastructure, technology and production processes, which promotes operational efficiency (+) but create environmental problems (-) High capital costs: the transition to RES-powered heavy industry (-) High implementation costs: introduction of advanced digital technologies involves large investment (-) High repair and replacement costs - faulty technologies can lead to significant repair costs, equipment replacement and production downtime(-) Ethical and moral dilemmas - The process of humanising artificial intelligence can raise a number of ethical and moral dilemmas, such as concerns about emotional manipulation, which can lead to social resistance and uncertainty about AI applications in everyday life(-)	T/E/S	D/CE
* Types: Political (P), Economical (E), Technological (T), Capacity/Awareness (C), Network (N), Social (S) ** Dimension: Decarbonisation (D), Circular Economy (CE), Sustainability (S)				

C.4.5 Cross-sectoral relations, trade-offs and feedbacks

Representatives from the automotive, energy, machinery and mining industries participated in the regional workshop. Their opinions make it possible to identify some cross-sector relations. The discussion made it possible to identify other types of connections as well.

The mining industry and in particular the coal mining industry will be regionally one of the most affected as a result of the decarbonisation processes taking place. Its relationship with other industries in this process is multifaceted. On the one hand, it is a pool of skilled workers who are a valuable resource. On a retraining basis, these individuals can support other industries gaining importance for decarbonisation, circular economy or sustainable development in the transition process. The rationale for such a relationship is already being observed in the region. Miners are involved in the development of the energy sector. The energy industry is increasingly tapping into the potential of mining and post-mining sites as sites for green energy production (heat from mines, PV farms on post-mining sites, wind farms). The move toward circularity in the region will benefit from the vast experience and density of companies related to waste disposal and which are now the backbone of the mining industry. Mining is also a highly advanced machinery industry. These companies are already implementing energy, electromobility projects. On the other hand, the relationship in terms of transfer of advanced knowledge between the region's developed automotive and machinery industries is becoming more and more outlined.

The recycling industry may be a future Polish (and perhaps European) hub for disposal of waste associated with industrial decarbonisation. There are some indications that this is quite acceptable. Statistics of NIMBY conflicts in Poland indicate that only about 10% of them involved waste management investments: landfills, incinerators, sorting plants, waste treatment plants. The region has a strong social imprint of the negative consequences of years of environmental neglect in the operation of industry. Appropriate formulation of information about the recycling industry will increase social acceptance. In addition, the multitude of degraded areas in the region reinforces the desire for transformation including perhaps acceptance of the development of these industries. The relationship between these industries could be the disposal of PV panels, wind turbines, electric cars, batteries and accumulators, advanced electronics. New material recovery and recycling technologies may need to cover additional energy needs. This could build a new relationship between this industry and energy in the form of nuclear power and RES in the region.

The automotive industry is outlining a strong new relationship with the region's energy sector for electromobility. Poland's automotive industry is strongly linked to the value chains of traditional internal combustion motorisation. The relationship with the region's energy and especially technology leaders will determine the region's ability to integrate into electric cars production chains. Another relationship captured during the workshop was that resulting from the prospect of building nuclear power plants and RES facilities. Cheaper energy can ensure that the automotive industry remains competitive, for example, against growing competition from Chinese companies. Automotive is building relationships with some of the region's most growing industries: IT and Industry 4.0. The flow of technology, the flow of workers can be an important element on the road to electromobility (decarbonisation of the region), sustainable transportation, automotive innovation. The region's IT industry may also be key to the growing need for AI and the labor deficit in this element.

The IT industry is permeating industrial activities in the region and can be very significant in the transformation process. Its relationship is already evident with the region's energy sector (heat pumps, advanced metering and smart systems for industry). Some parallels to the IT industry and its relationship with industry are industries under the umbrella term 'industry 5.0'. Their share is growing in the region's economy and their role in the transformation will be determined both by the recipients of their solutions and by the innovations created by these companies (e.g., creating the professions of the future in industry, attracting foreign capital, increasing R&D funding, supporting transformation modelling).

C.6 Synthesis I: Uncertainties and knowledge gaps

During the workshops, stakeholders, including industry representatives, experts, and local authorities, highlighted key sources of uncertainty regarding the economic transformation of the Silesian region, which is heavily reliant on the mining industry. One of the main topics of discussion was political and regulatory uncertainty. Participants emphasised that Silesia is at a critical juncture, and the lack of clear and stable governmental decisions regarding energy and climate policy makes planning difficult. The absence of a cohesive strategy for phasing out coal and the instability of legal regulations related to renewable energy sources (RES) make both investors and businesses hesitant to commit to long-term decisions. The ambiguity around whether the region should develop nuclear energy, focus on renewable energy, or continue supporting conventional energy sources adds another layer of uncertainty.

Another frequent topic of discussion was the pace of development of new technologies, which will be crucial for the future of industry in Silesia. Industry representatives pointed out that while there are many promising technologies, such as energy storage, hydrogen energy, or industrial decarbonisation solutions, it remains unclear when these will be available on a large scale. One example is hydrogen technology, which could play a key role in decarbonising heavy industry but is still in the experimental phase. Workshop participants expressed concerns that the lack of access to such technologies could leave the region lagging in the transformation process, which could negatively impact the local economy.

Uncertainty about the availability and cost of raw materials was also widely discussed. The energy transition in Silesia, which requires, among other things, the expansion of renewable energy infrastructure, is tied to the acquisition of resources such as lithium, cobalt, and copper. Participants noted the growing global demand for these materials and the risks associated with their limited availability. It was also discussed that Silesian enterprises will have to compete for these resources with other sectors worldwide, potentially delaying key transformation projects.

Geopolitics and its impact on global supply chains were another topic of concern. In the context of Silesia, participants emphasised that the energy transition and industrial modernisation require technologically advanced components, such as semiconductors, solar panels, or wind turbines. However, the changing international situation, especially conflicts in Ukraine and the unpredictability of trade policies, could disrupt the supply of these crucial components. Workshop participants voiced concerns that potential trade sanctions or other geopolitical disruptions could cause delays in investment projects and drive costs up.

Climate change, its consequences, and the risks it poses to the region's industrial infrastructure were also important points of discussion. Industry representatives highlighted that extreme weather events, such as floods or severe storms, are becoming more frequent and could threaten the stability of industrial and energy infrastructure in Silesia. Participants stressed the need to adapt existing facilities and expand energy infrastructure in ways that are resilient to changing climatic conditions, which adds additional costs and uncertainty.

Stakeholders also pointed to social reluctance to change as one of the key sources of uncertainty affecting the industrial transformation of the Silesian region. The region has been known for decades for its coal mining industry, which still covers a significant portion of the country's energy needs. Therefore, the inevitable transformation of Poland's energy system raises strong emotions. Currently, the country is in a transitional phase, with general strategy on the future energy mix included in National Energy and Climate Plan[28]. The government is proposing the development of nuclear power plants, but workshop participants noted that public fear of nuclear technology could significantly hinder these investments. Social concerns, especially in a region deeply rooted in the coal industry, are understandable but also represent a significant barrier to the transformation.

One of the most emotionally charged topics was the social issue and the future of the job market in the region. Silesia is heavily dependent on heavy industry and mining, meaning the energy transition will have a direct impact on thousands of jobs. Workshop participants emphasised that the lack of an adequate plan for workers in these sectors could lead to serious social problems, including rising unemployment and social unrest. Therefore, it becomes crucial to ensure retraining programs and create new jobs in green economy sectors. However, many expressed concerns that the pace of these changes would be too slow to compensate for the loss of traditional jobs.

Finally, workshop participants highlighted that unforeseen economic crises could have a significant impact on the pace of the region's transformation. Financial crises, fluctuations in raw material prices, or global economic slowdowns could limit the investment capabilities of both companies and the state. The COVID-19 pandemic was frequently cited as an example of a crisis that delayed the implementation of many green transformation projects, showing how sensitive the entire process is to unexpected external events.

A particularly challenging issue highlighted by the workshop participants was the sectors of industry that may have difficulty achieving zero emissions. The chemical industry, which produces plant protection products, and cement plants, of which there are many in the region, pose serious challenges for Silesia's decarbonisation. Industry representatives stressed that completely eliminating emissions in these sectors is difficult due to the nature of the production processes, which require large amounts of energy and raw materials. There is concern that without appropriate innovations, these industries will be forced to reduce operations or relocate abroad, which would negatively affect the region's economy and workforce.

All these factors—social resistance, geopolitical risks, lack of access to modern technologies, and the challenges of decarbonising key industrial sectors—make the economic transformation of the Silesian region a challenge full of uncertainty. Stakeholders agreed that long-term plans, state support, and investments in innovation are necessary to successfully navigate this difficult process and reduce the risk of delays and destabilisation of the regional economy.

C.7 Synthesis II: Key transformation challenges in the region

In the Silesia region, stakeholders identified several challenges that need to be overcome in the transformation process. After analysing them, we were able to group them into thematic groups that encapsulate individual ideas. Each of these thematic groups is key to ensuring that the transformation can be carried out in an effective and equitable way, giving opportunities for local social groups and enabling the development of the region.

Transition from Coal and Decarbonisation of Industry

A major challenge is reducing the region's reliance on coal and fossil fuels, which have long been central to

[28] https://www.gov.pl/web/climate/national-energy-and-climate-plan

its economy. Key industries such as mining, metallurgy, and the automotive sector must undergo deep decarbonisation. The shift to electromobility in the automotive sector, for example, requires substantial investments in retooling production lines and establishing electric vehicle supply chains. In metallurgy, reducing the reliance on coking coal remains difficult due to entrenched practices and economic dependence, necessitating alternative approaches like hydrogen metallurgy and new technologies for carbon-free steel production.

Technological Barriers and Innovation Gaps

The region faces limitations in accessing and adopting efficient technologies that are essential for the zero-carbon transition. High costs, inadequate infrastructure, and an innovation gap present significant hurdles to deploying new energy systems, including renewable energy sources and hydrogen technologies. Although the development of a hydrogen economy could aid decarbonisation, the region lacks the necessary infrastructure for hydrogen production, storage, and distribution[29]. Additionally, breakthrough technologies, such as nuclear fusion and advanced battery innovations, hold transformative potential but remain in development stages.

Restructuring the Labor Market

As traditional industries like mining and heavy manufacturing decline, the region must focus on reskilling and upskilling the workforce to align with emerging sectors such as renewable energy, advanced manufacturing, and digital technologies. There is a pronounced skills gap, especially in areas like artificial intelligence and automation, which limits the region's capacity to integrate new technologies and drive industrial innovation. Ensuring a just transition for workers, particularly those from coal-related sectors, requires targeted programs to facilitate career changes and foster motivation for lifelong learning.

Environmental Remediation and Sustainability

Environmental challenges are central to the region's transformation goals. The Silesian region must address persistent pollution issues, such as smog and contaminated industrial sites, by investing in modern pollution control technologies and implementing stricter regulations. Additionally, effective waste management solutions are required to handle the materials generated during the decarbonisation process, including recycling initiatives for batteries, photovoltaic panels, and other industrial byproducts. The rehabilitation of degraded industrial zones and brownfields is crucial to improving ecological conditions and supporting sustainable development.

Regulatory and Financial Hurdles

High costs associated with decarbonisation, along with new regulatory requirements like the Corporate Sustainability Reporting Directive (CSRD), pose financial and compliance challenges for companies. The multiplicity of decision-makers involved in the transition process complicates policy implementation and creates inconsistencies. To overcome these obstacles, the region needs a coordinated approach to financing, with better alignment between EU regulations and funding mechanisms. Incentives such as tax breaks, supportive legal frameworks, and stable legislation are essential to encourage innovation and attract investment.

In summary, the Silesian region's path to sustainable development requires addressing these key challenges through a holistic approach that integrates industrial restructuring, technological innovation, environmental

[29] There is a 'Polish Hydrogen Strategy to 2030. It envisages the creation of Hydrogen Valleys, including one in Silesia. The information was given about the decision to build a hydrogen plant in the region. The goal of its operation: decarbonisation in transport and energy sector. More info: https://tvpworld.com/82834196/poland-to-build-hydrogen-plant-in-silesia

sustainability, and social adaptation. By focusing on overcoming these barriers, the region can successfully navigate its transformation and achieve a resilient, low-carbon economy. Figure 30 below provides a schematic overview of key interdependencies related to the industry transformation in Silesia as identified during the stakeholder engagement.

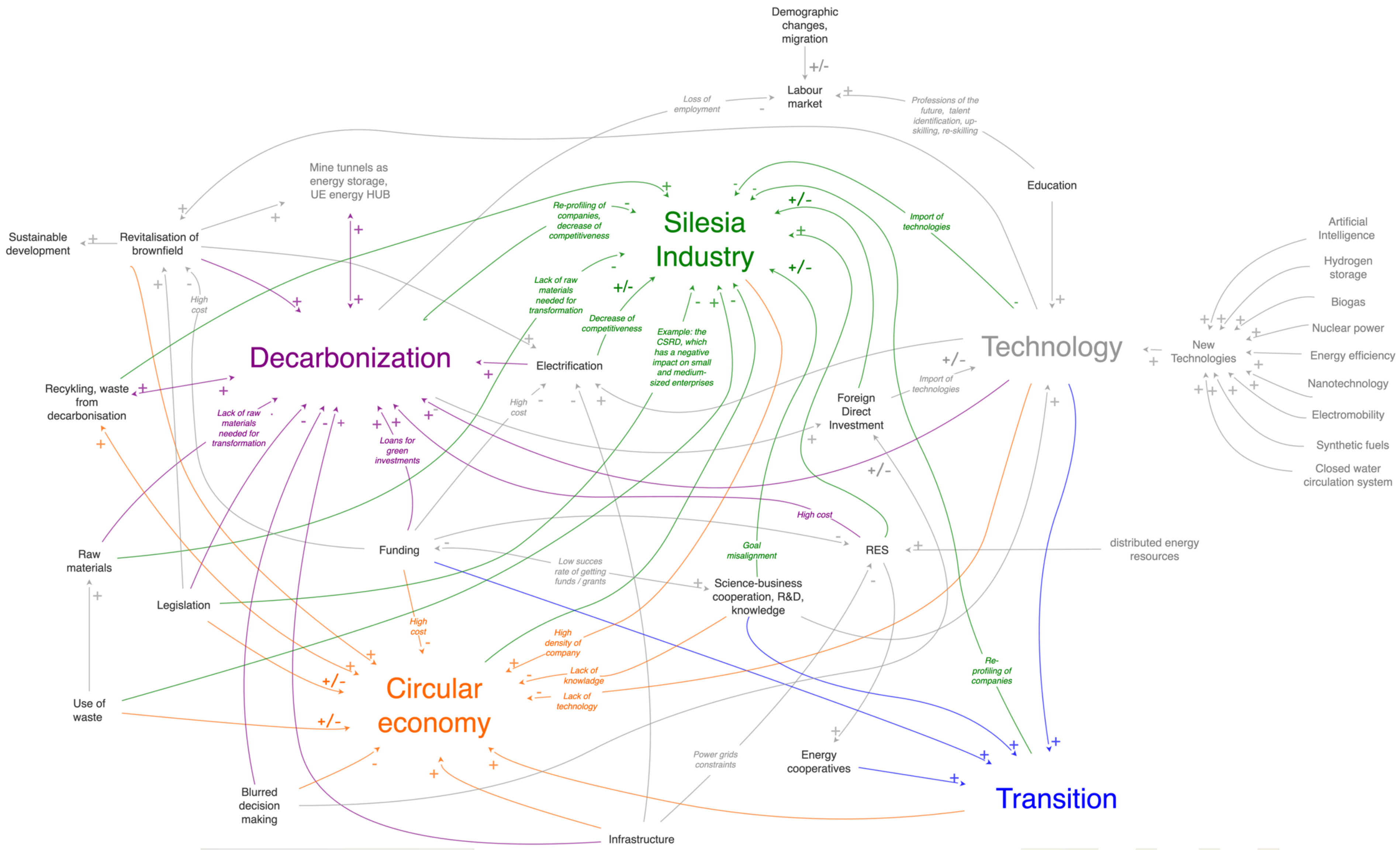

Figure 30. Causal map of key interdependencies related to industry transformation in Silesia.

Annex D: Rotterdam Regional Case Study

Gergő Sütő, Li Shen, and Ernst Worrell

D.1 Introduction

There is an increasing demand for integrated, economy-wide approaches to address climate action, resource efficiency, and circularity. Existing modelling capacities often fall short in capturing the complex interplay between circular economy initiatives and decarbonisation, particularly within energy-intensive industrial sectors. The TRANSIENCE project seeks to address this gap by developing MIC3, an open-source model ecosystem designed to assess the feasibility and impacts of various industrial transformation pathways. By incorporating input from regional stakeholders, TRANSIENCE ensures MIC3 is well-aligned with the specific challenges and opportunities that regional actors face in their transition to a climate-neutral and circular economy.

This report presents a case study on the Port of Rotterdam (hereafter: Port) in South Holland, the Netherlands, selected for its industrial significance, particularly in the refining and chemical sectors. These sectors face substantial challenges in progressing towards decarbonisation and circularity while maintaining global competitiveness, adapting to evolving energy landscapes, and reducing reliance on fossil fuels for both energy and feedstock.

The insights from this case study will inform upcoming stages of the TRANSIENCE project, including the development of policy-relevant research questions and the validation of MIC3 through further case study analysis in future stages. The remainder of this report presents insights from a review of academic and non-academic literature complemented with a series of expert interviews.

D.2 Background

D.2.1 Description of the region

The Port of Rotterdam is Europe's largest seaport situated near the city of Rotterdam, in the Rhine-Meuse-Scheldt delta of the Netherlands. It covers an area of 120 square kilometres and spans 42 kilometres in East-West direction (Port of Rotterdam Authority, 2024). The Port constitutes a cornerstone for the Dutch economy and facilities the needs of a broader hinterland in Europe.

Besides the function of port, the Port of Rotterdam also houses several industrial clusters on its territory. Industrial facilities are intertwined with cargo areas, directly enabling the processing and manufacturing of imported commodities; see Figure 31. The presence of the chemical industry is notable. Around 8% of the European Union's oil refining capacity and over 40 chemical producers are found in the Port.

Economic activities in the Port play a significant role in the Dutch economy. In 2022, the Port's added value amounted to 30.6 billion euros, or 3% of national GDP, and was growing (Port of Rotterdam Authority, 2024). It provided employment for 190,000 and induced altogether half a million jobs in the Netherlands. Moreover, the Port's refining and petrochemical companies are connected via a range of pipelines to industrial clusters in Belgium and North Rhine-Westphalia of Germany (ARRRA cluster), embedding them in the greater European industrial landscape.

While the Port spans over a large amount of land, it is also an area with limited opportunities for expansion.

It has already undergone two major extensions, once during the 1970s (*Europoort* area) and again in the 2010s (*Maasvlakte 2* area). The two projects combined doubled the Port's area by claiming land from water. Further expansion, if any, would likely be again directed seawards, but there are no considerable plans for such undertaking at the moment.

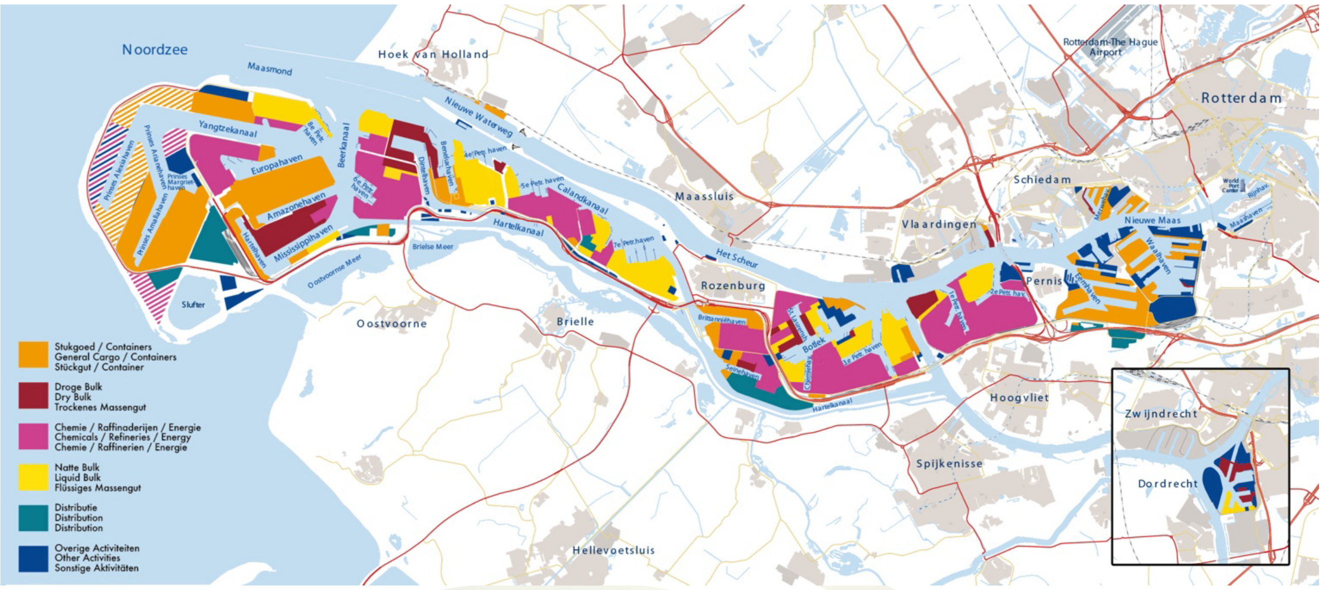

Figure 31. Map of facilities by activity type in the Port of Rotterdam[30]

Decarbonisation and circularity in the Port's industry

Stakeholders of the Port have expressed intentions in various agreements to work towards a decarbonised and circular port and industrial cluster.

At national level, the relevant policies are the Raw Material Agreement[31] from 2017 and the Climate Agreement[32] from 2019. The Raw Material Agreement set the ambition to halve the use of abiotic resources (minerals, metals and fossil carbon resources) by 2030 and achieve a 'waste-free' economy by 2050. Signatories agreed to draw up transition agendas for the topics of 1) biomass and food, 2) plastics, 3) manufacturing, 4) construction, and 5) consumer goods. The latest plans are elaborated in the 'National Circular Economy Programme 2023-2030'[33]. While the Port is not explicitly mentioned, the topics of plastics, manufacturing and consumer goods can be considered particularly relevant.

The Climate Agreement and connected Climate Law set out to reduce national greenhouse gas (GHG) emissions by 55% compared to 1990 (above the EU ambition) and reach climate neutrality by 2050. The agreement's intermediate target for Dutch industries – though not fixed in the law – is a reduction of 19.4 Mt CO_2 (or 35%) of emissions from 2015 to 2030. The Port's industries are mentioned to have the greatest reduction potential (10 Mt CO_2) over this timeline (p.86).

As part of a national programme called NOVEX, the Port is also one of the 16 selected regions where Dutch governments of various administrative levels (municipal, provincial, and national) are working together with

[30] Map adapted from https://rotterdamtransport.com/maps-port-of-rotterdam/
[31] Rijksoverheid. (2017). Grondstoffenakkoord.
[32] Rijksoverheid. (2019). Klimaatakkoord.
[33] https://www.government.nl/documents/reports/2023/09/27/national-circular-economy-programme-2023-2030

local stakeholders to create a comprehensive vision for the cluster's development until 2070 (Ministry of Interior & Kingdom Relations, 2022). This programme is particularly notable because it embeds the climate and circularity ambitions for the Port in relation with its surrounding region (e.g. urban, agricultural and natural areas) as well as other industrial clusters in the Netherlands. The programme is ongoing since 2022. Intermediate proposals were recently presented to companies via a public webinar, organised by Deltalinqs, the association for companies in the Port.

Corresponding to the plans, a transition of feedstocks – away from fossil carbon to renewable and low-carbon resources – seems to be undergoing. The report *'A Sustainable Carbon Future – Feedstock Transition for Harbor Industrial Complex Rotterdam'*, co-authored by Deltalinqs, explores the possibilities of replacing crude oil with a mixture of bio-based, circular and captured carbon sources, while maintaining production throughput (Power2X & Deltalinqs, 2022). Projects are under development to operationalise these plans. Most notable are the building of bio-refineries (e.g. Neste, Shell), construction of a hydrogen network within the Port (e.g. H-vision[34]) and development of CCS/U facilities at scale (e.g. Porthos[35]).

Table 12. Main stakeholders of industry identified in the Port of Rotterdam

Category	Stakeholders
Governmental	Municipality of Rotterdam; Province of South Holland; Ministry of Infrastructure & Water Management; Ministry of Economic Affairs; Ministry of Interior & Kingdom Relations; Waterschap Hollandse Delta (water authority)
Companies & associations	Deltalinqs; VNCI (Royal Association of Dutch Chemical Industry); Shell; BP; Exx-onMobil Corporation; Kuwait Petroleum Corporation; VPR Refining Group; Lyondell-Basell Industries; Neste Corporation; Corbion; DuPont de Nemours; DSM-firmenich; Alco Energy Rotterdam
Research organisations	TNO (Netherlands Organisation for Applied Scientific Research); PBL (Netherlands Environmental Assessment Agency); Delft University of Technology; Drift (Dutch Re-search Institute for Transitions); Erasmus University Rotterdam; CE Delft
Civil society	Natuur & Milieu (English: *Nature & Environment*); Institute for Sustainable Process Technology (ISPT); DCMR Environmental Protection Agency; Planet B.IO
Development agencies	Innovation Quarter; SmartPort
Unions	FNV Process industry; FNV Ports

D.2.2 Justification of case selection

The present case study focuses on the activities of refineries and chemical industries in the Port of Rotterdam. The relevant areas are demarcated with pink colour in Figure 31. The associated 5 oil- and 6 bio-refineries and over 40 chemical producers not only constitute the vast majority of industrial activity in the Port. Additionally, they are also the ventures most relevant for TRANSIENCE. A better understanding of factors governing the shift away from fossil carbon resources in the production of chemicals can enrich the development of the MIC3 modelling framework, particularly in the angle of plastics production, one of the focus materials of the project.

D.2.3 Key industrial clusters in the region and their relevance

In 2023, the Port of Rotterdam as a whole added 30.6 billion euros of value, which is about 3.2% to the GDP of the Netherlands (Port of Rotterdam, 2024). In this share, refineries and chemical industries directly

[34] http://www.h-vision.nl/
[35] http://www.porthosco2.nl/

represented about 6.6 billion euros, with further indirect contributions that were not found publicly available at the disaggregated level (Streng et al., 2023). The direct value added of the chemical sectors has been relatively stable pre- and post-COVID with a dip of 36% only in 2020. Refineries experienced greater fluctuations in this measure, with negative 0.4 billion euros direct GVA in 2020, followed by a tripling to 4.6 billion in 2022 compared to 2018.

When it comes to employment, the Port provided 140 thousand direct and 85 thousand indirect jobs in 2022 (ibid.). The refinery and chemical industries in the Port employed around 11 thousand people directly. Employment for refining activities appears to have gradually shrunk to 6,400 in 2022, a reduction of about 8% from 2018. Chemical activities, on the other hand, shown a slight increase from about 4,400 to 4,600.

CO_2 emissions of the Port have incrementally decreased from 30.6 Mt CO_2 in 2016 to 22.6 Mt in 2022 (Port of Rotterdam Authority, 2024, p.35). In 2022, oil refineries can be attributed 40% of these emissions (9.1 Mt) and chemical industries another 20% (4.6 Mt). Other industries constitute only 5% of CO_2 emissions, while the rest comes from fossil-based power generation with coal-based power at 28% (5.7 Mt) and natural gas-based power at 8% (1.9 Mt). These figures for 2022 are in line with trends from previous years. The Port has the ambition to reduce emissions by 55% until 2030, although they are still above 1990 level when emissions were at 20.7 Mt. In 2023, the Port of Rotterdam as a whole added 30.6 billion euros of value, which is about 3.2% to the GDP of the Netherlands (Port of Rotterdam, 2024). In this share, refineries and chemical industries directly represented about 6.6 billion euros, with further indirect contributions that were not found publicly available at the disaggregated level (Streng et al., 2023). The direct value added of the chemical sectors has been relatively stable pre- and post-COVID with a dip of 36% only in 2020. Refineries experienced greater fluctuations in this measure, with negative 0.4 billion euros direct GVA in 2020, followed by a tripling to 4.6 billion in 2022 compared to 2018.

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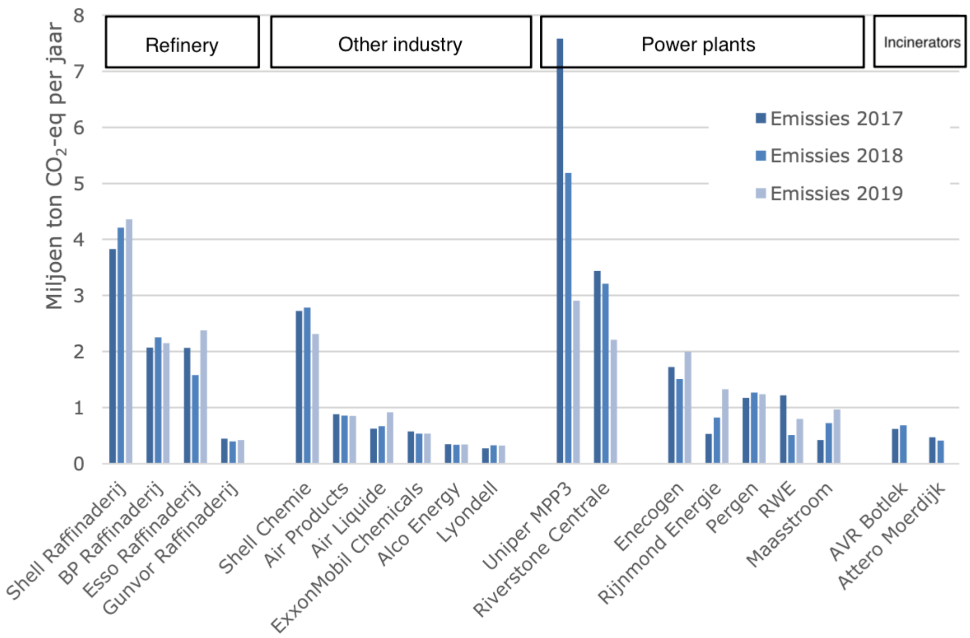

Figure 32. Installations with the largest GHG emissions in the Port of Rotterdam. All companies with annual emissions above 0.25 MtCO2e are shown (Van Dril et al., 2021).

Furthermore, a detailed representation of energy and feedstocks flows is shown in Figure 3 for the year 2016. While somewhat outdated, this figure is the best in-depth representation of these flows found in the literature investigated. Main changes since 2016 have mostly appeared in the supply of electricity (Dutch: *elektriciteitsopwekking*). The predominance of refinery ('*raffinage*') output to fuel production (1900 PJ) over chemicals (190 PJ) is noteworthy. This balance is likely to change as the demand for fuel is expected to decline with the electrification of transport while the demand for chemicals, especially for plastics, will stay or further increase.

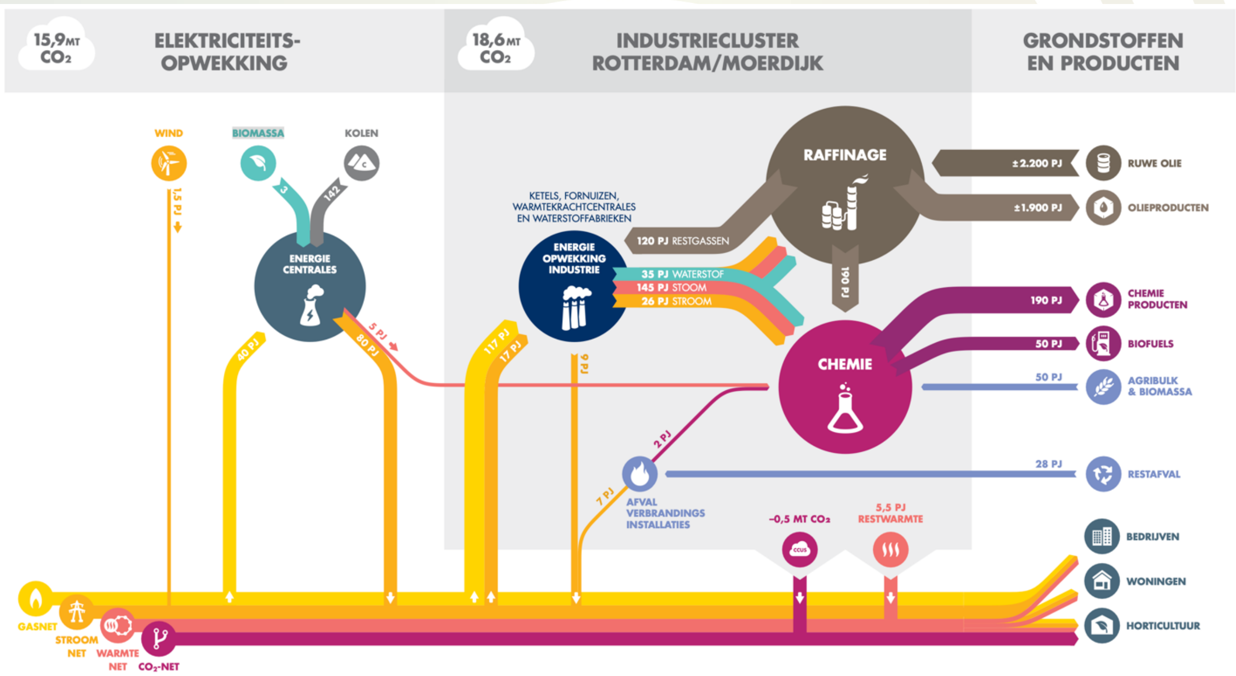

Figure 33. Energy and feedstock flows in the Port's industry clusters in 2016 (Werkgroep Industriecluster Rotterdam-Moerdijk, 2018).

D.3 Case Study Method

The Port of Rotterdam case study was conducted primarily through a review of existing academic and non-academic literature, complemented by insights gathered from expert interviews. Despite several efforts to organise a stakeholder workshop, including three rounds of invitations (via emails and phone calls) to industry associations, port management, and local authorities between March and August 2024, we were unable to secure participation. Additionally, we attended two relevant events organised by the Port in June to engage potential stakeholders in the workshop; however, responses remained limited.

Given the extensive discussions on decarbonisation and circularity transitions that have taken place among stakeholders in recent years, many perspectives and strategic insights are already documented in various roadmaps, strategy reports, position papers, public statements, and scenario studies. We identified a total of 21 publicly available documents that are relevant in this context.

In August and September, we adjusted our research approach to rely primarily on an in-depth review of these available strategy documents. This shift was guided by the observed limited interest in a workshop among contacted stakeholders, and the recognition that these documents reflect contributions from many of these same stakeholders. The document review was then supplemented with five targeted expert interviews, aimed at capturing additional insights or recent developments that were not covered in the reviewed reports.

The following sections summarise findings from both the 21 strategy documents and the expert interviews conducted in August, September, and October 2024. Section D.6 provides a comprehensive list of all documents reviewed. The expert interviews included diverse perspectives from a policymaker at a local authority, an academic researcher specialising in spatial planning for port-cities, an energy systems modeller at a national research organisation, a policy advisor from a national agency, and a senior chemist-researcher from a major oil and gas company. Every expert had in some way been involved with discussions around circular economy and decarbonisation in the context of the Port's industries.

D.4 Case Study Results

The circular economy paradigm has gained significant prominence as a strategic pathway for achieving decarbonisation targets, particularly for the industrial activities concentrated in the Port of Rotterdam. This approach emphasises reducing reliance on virgin raw materials and fossil-based feedstocks and maintaining materials within the economic system for as long as possible. In the Port, these circular economy principles closely intersect with decarbonisation goals. Shifting away from crude oil towards alternative sources of carbon—often referred to as the "feedstock transition" (Dutch: grondstoffentransitie)—is increasingly recognised as a core component of this strategy. The motivation behind this transition is further strengthened by national agreements such as the Netherlands' Raw Materials Agreement, which highlights the importance of resource efficiency. In this context, the Port's circular economy debates revolve around "circular carbon," an approach that seeks to identify and integrate alternative carbon feedstocks to replace crude oil inputs. If effectively implemented, these measures could substantially reduce CO_2 emissions from refineries and chemical production facilities, thus contributing to broader decarbonisation aims.

Within the Port of Rotterdam, the feedstock transition concentrates on three main categories of alternative carbon sources: bio-based feedstocks, plastic waste, and captured carbon. Each category contributes to closing the carbon loop, while also presenting distinct challenges:

- **Bio-based feedstocks:** These encompass both virgin biomass and various organic waste streams, such as used cooking oil. Used cooking oil, in particular, is often deemed a feasible option due to its relatively stable supply and compatibility with existing petroleum-based infrastructure. Current practices suggest that integrating such feedstocks can be achieved under certain conditions.
- **Plastic waste:** Processes such as pyrolysis can convert plastic waste into pyrolysis oil, which then serves as a feedstock for producing new chemical and plastic products. This circular approach reduces dependence on fossil-based inputs, but ensuring a stable and sufficiently large supply of suitable plastic waste remains difficult. The scale required by the Port's industrial sector surpasses the volumes likely to be sourced domestically.
- **Captured carbon:** Carbon Capture and Utilisation (CCU) involves capturing CO_2 emissions and repurposing them within various industrial processes. Although conceptually promising, CCU faces technological, economic, and energy-related hurdles that have limited its widespread adoption. Its precise role in the circular economy remains unclear, particularly given current priorities in research and policy.

The following section explores the most important dynamics which in some way pose a challenge to the above outlined feedstock transition in the Port of Rotterdam. These challenges have been identified from the combination of literature with interviews and comprise a diverse set of seven technical, economic, political and cluster dynamics.

D.4.1 Challenges in the way of transition

D4.1.1 Availability and compatibility of feedstocks

Ensuring a sufficient supply of appropriate alternative feedstocks remains a fundamental challenge for the Port of Rotterdam's feedstock transition. Currently, achieving this through domestic sources alone appears unlikely. For example, the prospect of meeting the Port's substantial demand with domestic plastic waste is impossible given the scale required by export-oriented industries. While access to a major harbour can facilitate feedstock imports, reliance on external sources also introduces uncertainties related to global supply chains and competition with other markets (Van Den Berghe, 2024).

The Port's industrial profile further complicates these supply issues. Approximately 80% of the crude oil processed within the Port is devoted to producing fuels (e.g., petrol and diesel), whereas only 20% is utilised in chemical production, including plastics. The conversion of oil into fuels—and their eventual combustion—prevents carbon from being recycled within the economic system, thereby obstructing carbon circularity. The use of biomass is another potential route, including the added benefit of carbon sequestration during vegetation growth. This pathway, however, raises land-use dilemmas since sourcing virgin biomass competes directly with existing agricultural production. Even under optimistic scenarios, the combined availability of plastic and biomass feedstocks is projected to replace not more than 40% of current crude oil use by the Port's industries (Power2X & Deltalinqs, 2024).

D.4.1.2 Spatial constraints

Recent research on the spatial implications of decarbonisation in the Port suggests that a scenario involving heightened circularity would require much more storage and processing space than the Port currently possesses (Detz et al., 2021). Meeting these spatial demands may necessitate importing pre-processed feedstocks, such as pyrolysis oil, rather than handling large volumes of raw plastic waste on-site. Doing so could alleviate some of the logistical pressures and infrastructural requirements associated with on-site sorting, cleaning, and conversion of waste materials.

The longstanding clustering of industries in the Port has historically supported operational efficiencies and collaborative ventures. However, this cluster dynamic presents both opportunities and challenges for the transition. Established networks and governance frameworks (e.g., those facilitated by the Port Authority and Deltalinqs) may expedite the development of shared infrastructure solutions. Yet, competitive tensions between firms may impede collective decision-making. Divergent corporate strategies, risk tolerances, and investment horizons can hinder agreement on joint initiatives, complicating the spatial arrangements needed to accommodate new feedstocks.

Moreover, certain alternative feedstocks, such as biomass, have lower energy density compared to crude oil. This characteristic necessitates larger volumes—and consequently more storage space—to achieve the same energy or feedstock value. Given the Port's spatial limitations, accommodating such increased storage requirements without significant infrastructural modifications or spatial expansions will be challenging.

D.4.1.3 A diversity of industrial processes

The Port's industrial ecosystem encompasses numerous interconnected processes. While this diversity can offer flexibility—allowing one process to compensate for disruptions in another—it also complicates change. Infrastructure tightly integrated and optimised for traditional feedstocks does not easily adapt to alternative inputs. Introducing new feedstocks may require simultaneous adjustments across multiple facilities and value chains, increasing complexity and reducing the capacity to adapt swiftly (Van Kranenburg et al., 2021). An advantage for the Port of Rotterdam is the plurality of activities. Most industrial processes are operated at more than one location and due to the symbiotic connection between facilities, one process can act as a substitute to another. One interviewed stakeholder remarked that this flexibility grants technically allows for a more step-by-step transition to more sustainable industrial processes.

D.4.1.4 The role of carbon capture

Carbon Capture and Storage (CCS) is often viewed as a short- to medium-term measure for reducing industrial CO_2 emissions. However, its long-term effectiveness is uncertain, especially given limited storage capacity under the North Sea and concerns that prioritising CCS might detract from the development of more inherently sustainable solutions (Van Dril et al., 2021). Carbon Capture and Utilisation (CCU) technologies enable the use of captured CO_2, combined with hydrogen, in the production of new chemical products. Industry roadmaps calculate with some level of capture carbon as an alternative feedstock. This technological route is estimated to be able to replace at most 10% of the crude oil use at current production levels (Power2X & Deltalinqs, 2022). However, experts have pointed to very high overall energy requirements of producing chemicals using CCU, not least due to the energy inefficiency of obtaining (green) hydrogen. Therefore, even if crude oil demand declines with the electrification of mobility, the role of carbon capture for chemical production is expected to remain marginal within the overall system.

D.4.1.5 Clustering: balancing cooperation and competition

The strong clustering of industrial actors within the Port has historically enabled resource sharing, knowledge exchange, and infrastructural synergies. Interviews indicate that this clustering can both support and hinder the feedstock transition. On the one hand, collaborative efforts—such as joint pilot projects or co-financed infrastructure—can reduce costs, accelerate innovation, and boost collective resilience (Schneider et al., 2020). On the other hand, companies remain competitors, and concerns about resource security, intellectual property, and market positioning can deter cooperation.

For many firms, securing access to alternative carbon feedstocks is crucial. This imperative may encourage collaboration, yet it also heightens competitive sensitivities. Governing such complexity often requires enhanced governance structures to facilitate dialogue, foster transparency, and enable equitable sharing of risks and benefits. Existing bodies, such as the Port Authority and Deltalinqs, already coordinate and guide industrial planning. Their role in shaping decarbonisation and feedstock strategies is likely to intensify as the need for collective action becomes ever more evident (Drift, 2024).

D.4.1.6 Another energy transition

The pursuit of decarbonisation in the Port is not limited to feedstock transitions. Electrification represents another major avenue, especially for chemical producers. While the Port currently exports electricity, scenarios involving extensive electrification suggest it may become a net importer, thereby increasing demands on the national and regional electricity grids.

This shift is constrained by existing grid capacity limitations. Grid congestion is already a national concern, and any significant increase in industrial electricity consumption will exacerbate these problems. Expanding and upgrading grid infrastructure is thus essential, but remains costly, time-consuming, and subject to regulatory hurdles. Moreover, as the Port seeks to integrate alternative feedstocks for plastic production, these plans must compete for resources and attention with non-industry energy transition, adding complexity to long-term strategic decision-making.

D.4.1.7 Policy barriers

Policy and regulatory frameworks in the Netherlands and the European Union play a pivotal role in directing decarbonisation trajectories. Companies in the Port have expressed concerns about policy volatility and the lack of stable, long-term regulatory signals that can underpin investment confidence (Deltalinqs, 2024). Although government support is available for certain technologies, shifting priorities at the national level can undermine strategic planning, delay investment decisions, and introduce uncertainty.

European regulations, such as RED3, often specify certain technologies, potentially limiting innovation by imposing rigid routes rather than more overarching goals, such as emissions reduction targets. Such specificity can oblige firms to invest in options that may not align well with their operational realities.

Moreover, policy support for biomass in the European Union remains largely focused on fuels rather than chemicals, leaving biomass-based chemical production unsubsidised and underdeveloped compared to fossil-based equivalents. This imbalance places biomass-derived chemicals at an economic disadvantage, inhibiting their integration into existing value chains and slowing progress towards circularity.

D.4.2 Modelling capacities of stakeholders

Stakeholders in the Port of Rotterdam area vary significantly in their capacity to conduct in-house modelling studies to support decision-making. Two main groups with substantial modelling capabilities stand out: research organisations and large multinational corporations. Research organisations, such as TNO and PBL, have extensive experience conducting scenario studies and maintain a range of sophisticated models in-house. In some cases, models for a specific industrial area, e.g. a cluster within the Port, are developed on-demand. These organisations are often commissioned by public sector entities or industry associations that either lack the resources to develop their own models or prefer to rely on independent, trusted third parties to ensure objectivity in their analyses. This impartiality is crucial when unbiased insights are required to guide policy and strategy.

In contrast, large multinational corporations, particularly in the oil, gas, and petrochemical sectors, also possess strong in-house modelling teams. However, unlike research organisations, these companies often use proprietary models to assess economic, energy, and climate scenarios specifically for their business needs. The primary objective of these corporate modelling efforts is to evaluate how future market, and regulatory developments might affect their operations and profitability. While these models provide valuable insights for the companies themselves, they are typically not made available to the broader stakeholder community, limiting their use in public or cross-sector decision-making processes.

Table 13. Overview of key challenges, drivers and barriers identified in the Port of Rotterdam Case Study.

Key word	Challenges	Drivers (+) / Barriers (-)	Type *	Dimension**
Availability	A limited availability of alternative carbon feedstocks to replace fossil ones.	Access to harbour for feedstock imports (+) Sourcing virgin biomass competes with food production (-) Using carbon feedstocks for fuel production prevents carbon circularity (-)	E / P	CE / S
Space	Maintaining throughput with alternative carbon feedstocks would require expansion in an already constrained area.	Low energy density of alternative feedstocks means more space for storage and processing (-) Port is situated in a densely populated surrounding (-) Sea-ward expansion demonstrated in the past (+)	T / C	CE
Process dependency	Inter-dependence of industrial processes requires coordination of transition efforts.	Due to existing industrial symbiosis, processes depend on one another, especially in clusters within the Port (-) Variety and plurality of industrial processes in the Port grants flexibility for step-by-step transition (+)	N / T	D / CE
Carbon Capture and Utilisation	The premise of CCU to enable a 'circulation' of carbon is offset by high energy requirements.	Technical potential to reduce CO_2 emissions while also avoiding fossil carbon extraction (+) Very high overall energy use places the benefits of CCU under question (-)	T	D / CE
Clustering	Industry clusters need to balance cooperation with competition as the transition progresses.	Demonstrated collaborative governance structures in place (+) Potential cost reductions through cooperation for infrastructure, pilot projects, etc. (+) Keeping a competitive edge can hinder cooperation (-) Securing access to alternative feedstocks remains critical to companies (+/-)	N	D / CE
Energy	Energy transition in the Port contests with non-industry energy transition.	Grid congestion is an ongoing country-wide issue (-) Proximity to North Sea grants easier access to offshore wind power (+) Non-industry energy transition also demands renewables (-)	T	D

Key word	Challenges	Drivers (+) / Barriers (-)	Type *	Dimen-sion**
		Hydrogen electrolysis can make optimal use of the intermittency of renewable energy sources (+)		
Policy	Despite existing policy attention, advancements are needed to steer industry decarbonisation in the most circular way.	Fuel-focused policy landscape hinders innovation for chemicals (-) Policies are often overly technology-specific, instead of setting overarching goals (-) High leverage as major industry cluster (+)	P	D / CE
* Types: Political (P), Economical (E), Technological (T), Capacity/Awareness (C), Network (N) ** Dimension: Decarbonisation (D), Circular Economy (CE), Sustainability (S)				

D.5 Synthesis: Key transformation challenges, uncertainties and knowledge gaps

Based on insights from the literature review and interviews, several key factors have emerged that are key for the Port of Rotterdam's industrial feedstock transition. The interrelation of challenges is visualised in a causal loop diagram shown in Figure 3. This diagram can inform the development of the MIC3 modelling framework by highlighting the most important causal relations and their direction of influences. Three key area of knowledge gaps are identified which could benefit the most from modelling.

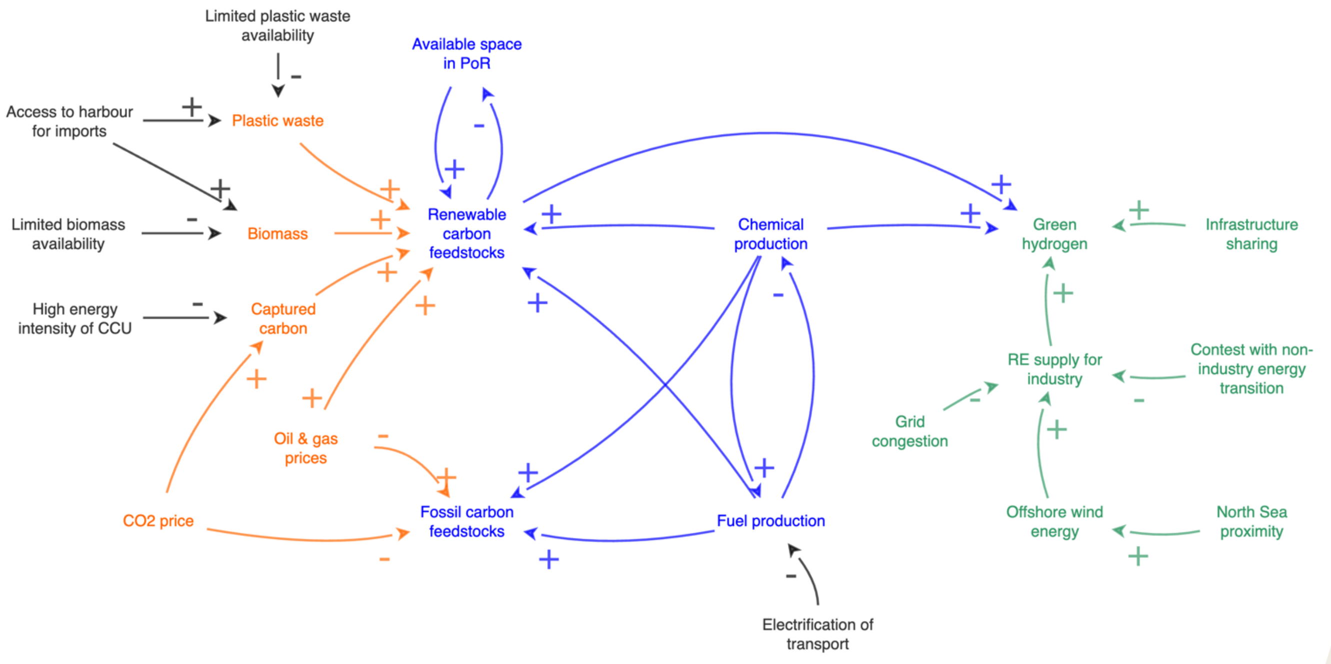

Figure 34. Causal mapping of key factors influencing the feedstock transition for chemical and fuel production in the Port.

First, the transition toward a more circular economy, particularly the circulation of carbon, has become a central consideration. In the Port, carbon is not only viewed as an output in the form of emissions but also as a vital input in the production of fuels and petrochemical products. However, the optimal mix of future feedstocks of carbon, whether bio-based, secondary, or captured, is not yet established, which presents opportunities to explore various alternative feedstock scenarios. Modelling potential feedstock mixes could offer valuable insights for stakeholders, helping them to align their strategies with circular economy principles.

Secondly, the spatial constraints of the Port have surfaced as a significant concern. The limited available space for expansion, combined with the need to accommodate industrial production facilities, storage, transportation, and infrastructure such as pipelines, makes spatial considerations essential for effective planning. The integration of spatial factors—such as facility locations, transportation networks, and opportunities for industrial symbiosis—into the modelling process will be crucial for ensuring the feasibility of proposed scenarios. These spatial elements should ideally be embedded in the MIC3 model's industrial modules or, at the very least, incorporated during the scenario design and validation phases to ensure that the results are both realistic and actionable.

Finally, the continued reliance on international imports of feedstocks, including alternative and renewable options, is likely to remain critical for the Port's industries. Many of the companies operating in the Port have global supply chains, with connections extending both within and beyond Europe. This underscores the importance of modelling global material flows and economic activity, as any meaningful scenario for the Port must consider international dynamics. Thus, the planned Global Material Flow Analysis module of the project’s MIC3 model is expected to play an important role in providing stakeholders with comprehensive, globally informed insights into the future of feedstock supply and demand.

D.6 Stakeholder documents for review

Table 14. Stakeholder documents on the decarbonisation and circular transition of industries in the Port of Rotterdam.

Stakeholder	Year	Title
Corbion	2024	Statement on Biobased or Renewable Feedstocks
Corbion	2024	Statement on Biobased Plastics in a Circular Economy
Deltalinqs	2024	*Reactie Deltalinqs op Hoofdlijnenakkoord*
Deltalinqs	2022	A Sustainable Carbon Future – Feedstock Transition for Harbor Industrial Cluster Rotterdam
Deltalinqs	2024	*Webinar NOVEX-opgave Rotterdamsehaven*
Drift	2024	The Raw Material Transition for the Port of Rotterdam
Port of Rotterdam, Government of the Netherlands, Province of South Holland, Deltalinqs, and Municipality of Rotterdam	2019	*Havenvisie 2030*
Government of the Netherlands	2021	*Plan van Aanpak NOVI Transitie Rotterdamse Haven*
Governments of the Netherlands, Municipality of Rotterdam, Port of Rotterdam, Province of South Holland	2024	*Ontwikkelperspectief NOVEX-gebied Rotterdamse Haven*
PBL	2021	*Verkenning Energietransitie Industriecluster Rotterdam*
PBL	2022	Decarbonisation Options for the Industry Cluster Botlek/Pernis Rotterdam
PBL	2020	Decarbonisation Options for ExxonMobil Chemicals Rotterdam
PBL	2021	Decarbonisation Options for Large Volume Organic

Stakeholder	Year	Title
		Chemicals Production, LyondellBasell Rotterdam
PBL	2020	Decarbonisation Options for Large Volume Organic Chemicals Production, Shell Pernis
Port of Rotterdam	2022	Resource Transition - Circular by 2050 (position paper)
Province of South Holland	2023	*Verduurzaming Industrie – In Drie Stappen naar een CO_2-emissiearme en Circulaire Industrie*
Royal DSM	2022	Integrated Annual Report - Sustainability statements
TNO	2021	Transition to E-fuels: a Strategy for the Harbour Industrial Cluster Rotterdam
TNO, SmartPort	2021	*Ruimtelijke effecten van de energietransitie: casus Haven Rotterdam*
Working group 'Industriecluster Rotterdam-Moerdijk'	2018	*In Drie Stappen naar een Duurzaam Industriecluster Rotterdam-Moerdijk in 2050*
Working group 'Leden van Klimaattafel'	2020	*Clusterplan industriecluster Rotterdam-Moerdijk*

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Annex E – Insights from the Brussels Stakeholder Workshop

E.1 Introduction

In her guidelines for the next European Commission, Ursula von der Leyen announced that strengthening the EU's industrial competitiveness, in line with the objectives of the European Green Deal, will be a top priority of the next European Commission. Specifically, she announced plans to introduce a new Clean Industrial Deal for competitive industries and quality jobs, as well as an Industrial Decarbonisation Accelerator Act to support industries and companies through the transition and a Circular Economy Act to create a market for secondary materials. However, there is still limited understanding of the complex, cross-cutting implications the twofold transition towards a circular and carbon-neutral economy will entail for European industry. This generates uncertainties, particularly in energy-intensive sectors, which ultimately affect investment decisions.

Modelling tools can help industry and policymakers navigate these uncertainties and close knowledge gaps. However, state-of-the-art modelling is not yet able to fully capture the interplay of these agendas. Two EU-funded Horizon Europe - Cluster 4 projects, TRANSIENCE and AMIGDALA, are tasked with developing new modelling capacities and providing evidence-based support for the European industry transition.

In this endeavour, we jointly organised a workshop to bring together key stakeholders from policy, industry, research, and civil society and to discuss and identify key transition challenges. Collaboratively, we explored realistic options to advance the EU industry's transition through improved modelling. In four workshops, a diversity of questions was addressed: what is the strategic importance of maintaining basic industrial production capabilities within Europe's borders? What are the major technological challenges and solutions for a low-carbon and circular industry? How does that political dimension (ambition and support) fit in, at the EU level? What are the most pertinent uncertainties, risks, lock-ins, and other factors jeopardising the current industrial status in Europe and/or hindering the effectiveness of a more sustainable, low-carbon, and circular paradigm? What business opportunities are there for industry to operationalise Europe's ambitions through global investments and regrets?

The workshop was split in two parts, such that participants could engage in two of the four topic groups. The second group was asked to build upon the results of the first group. This report synthesizes the results of the four different topic groups and gives an overview of the results.

Approximately 30 stakeholders from policy, industry, civil society and research joined the workshop together with approximately 20 researchers from the two projects.

E.2 Workshop Insights

E.2.1 Political dynamics as a transformation barrier and the role of EU ambition & leadership

In the first workshop, the role of political uncertainty in the transformation process was discussed, and how to address the fact that this can increase reluctancy towards green investments. The workshop was based on the insights from a previous similar workshop in a regional industrial cluster, where a causal loop diagram was constructed to visualise the relationships between investment, regulation, and external factors and uncertainties.

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The objective of this breakout session was to understand the political barriers to transformation, especially those that are increasing the investment backlog. Key questions addressed in this breakout were:

1. What are important barriers and enablers for investment? What have we missed?
2. How could these be addressed? How could political dynamics become an enabler for transformation?
3. What could the role of the Clean Industrial Deal be in solving the investment backlog?
4. Where are knowledge gaps? Where could models help?

Figure 1 shows the Causal Loop diagram which served as a basis for the discussion in the workshop and the post-its that were added based on the contributions of the participants. In the first part of the workshop, the causal loop diagram was validated and the addition of some concepts, especially competitiveness and energy prices, were discussed. Then instruments to address the prevalent investment backlog were discussed and added to the poster. In the second part of the workshop mainly the question of how models could help to address the corresponding knowledge gaps and uncertainties were discussed.

Figure 35. The board of the first workshop displayed the Causal Loop Diagram as a basis for discussion. Participants added their perspective on post-its.

E.2.2 Technological challenges and solutions for a low-carbon and circular European industry

European industry ought to raise its sustainability, carbon-neutrality, and circularity performance, all while maintaining its competitiveness. Technological advancements, alongside other innovative but non-technical approaches, and reinforced by a well-structured regulatory framework, are essential in driving progress toward achieving this objective. The objective of the second breakout session was to identify and prioritise the decarbonisation and circularity technologies/solutions that will enable the EU green industrial transition.

Key questions addressed in this breakout were:

1. What are the technologies and solutions across the energy efficiency and circularity, electrification and alternative sources, green hydrogen, and Carbon Capture, Use and Storage fields that will play a pivotal role in accelerating the decarbonisation and circularity of the EU industry?

2. Which challenges and barriers may be faced regarding their development, deployment, and

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implementation? How can we overcome them?

3. Which technologies/solutions should be prioritised and how?

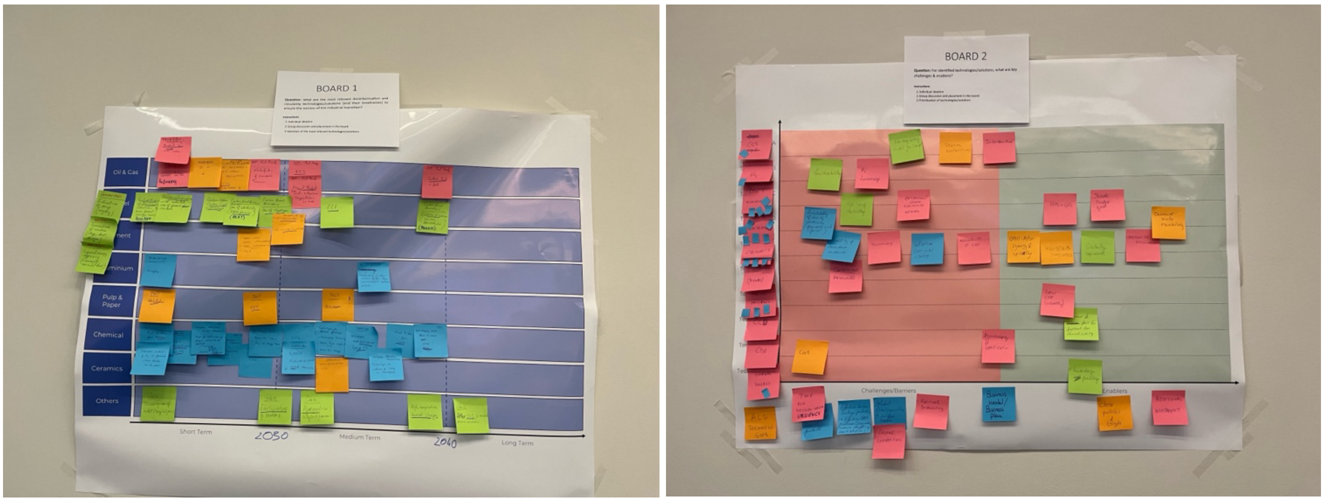

Figure 36. Photo protocol of the results of break-out 2.

Development of Business models to implement climate neutral techonologies and solutions

- Industries already know and have already identified the technologies and solutions required for their decarbonisation. At this point they only need to develop business models to promote and implement them. To this end industry concerns relate to:
    - **Urgency in decision-making:** given the horizon of climate objectives, industry needs assistance to develop their roadmaps and ensure its competitiveness NOW.
    - **Need of clear policies:** given the uncertain and unstable context, industrial assistants asked for a clear regulatory framework that will back up their investments and decisions
    - **Need of additional funding:** industry requires of additional funding to invest in decarbonisation and circularity technologies/solutions
- Electrification technologies and the adoption of circularity measures were identified as the priority solutions for achieving a low-carbon and more circular industry
    - **For electrification solutions**, the high cost of electricity and the need of enlarging and decarbonising grid networks were seen as major challenges. PPAs, and demand-side flexibility (including storage) were identified as enablers to promote electrification solutions.
    - **For circularity solutions,** low availability of secondary/recycled materials as well as still under-developed recycling technologies were the major barriers. Cross-sectoral synergies and industrial symbiosis were seen as enablers.
- CCS/U and CDR technological solutions, and to a lesser extent H2, caused debate. While these technologies were identified as potential solutions in the short term for oil & gas, steel, and chemical industries (medium-long term for the glass industry), they were not prioritised due to high costs and infrastructure needs. It should be noted that while mapping the different technologies across time horizons another debate arose: and that was whether place the technologies based on their technical or on their economic viability. Here again, opinions were diverse: some assistants noted that

these technologies were technically and economically viable for specific sectors, while others did not see CCS/U as a viable decarbonisation option at all.

E.2.3 Business opportunities for global industries to operationalise the green transition

To meet the twin transition objectives, existing and new products to meet customer demand need to be low-carbon, material-efficient and circular. Beyond products, the twin transition raises questions of industrial organisation within and beyond the borders of the EU, and therefore on what the future of industrial value chains looks like in and towards 2050.

The objectives of this breakout session were to provide a cross-industry view of what products need to emerge to meet the twin transition objectives, to sketch implications on the design of value chains, and to give consideration on what is the optimal industrial European organisation versus the rest of the world.

Key questions addressed in this breakout were:

1. For your sector, what products need to emerge to meet European decarbonisation and circularity objectives?
2. Assuming such products emerge, what are the implications for the respective value chains?
3. Given your current and future reading of European industrial competitiveness, what products need to be developed within the EU?
4. What dimensions of the value chain are critical to ensure European competitiveness?

This breakout is aimed preferentially at industry representatives so they may benefit from cross-fertilisation of different sector views on their future and jointly design a common view on the shape of European industry given twin transition objectives in a globally competing world.

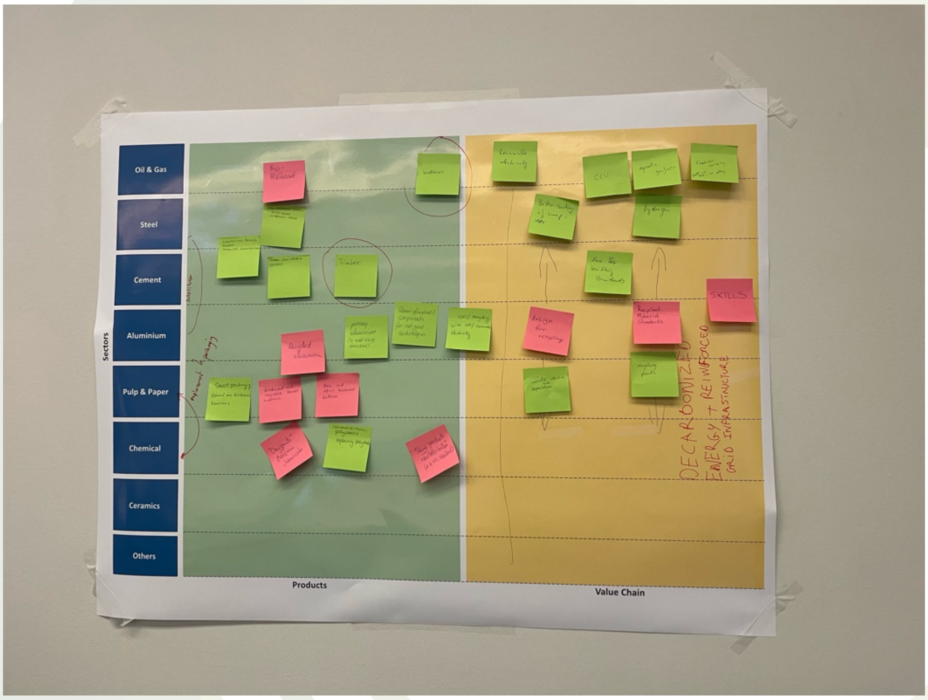

Figure 37. Photo protocol of the results of breakout 3.

Emerging Products and Key Themes

To align with Europe's decarbonisation and circular economy goals, industries are innovating with bio-based, low-carbon, and circular products. Key areas of focus include:

- *Bio-based products*: Adoption of bio-methanol, bio-crude, and bio-based plastics is expanding across sectors like oil, gas, and packaging.
- *Smart and sustainable alternatives:* New product categories, including smart packaging, electric vehicle batteries, and enhanced public transit options, support the shift from fossil-fuel dependency.
- *Material Substitution*: Industries are exploring substitutes like aluminium for steel and paper for certain chemical-based materials to reduce environmental impact.

Value Chain Implications

Achieving a circular, low-carbon economy demands major changes to industrial value chains. Essential components include:

- *Access to decarbonized energy and green infrastructure:* Consistent low-carbon energy, affordable hydrogen, and extensive recycling systems are foundational.
- *Transparency and policy alignment*: Effective value chains require transparent and science-based regulations that consider economic impacts and competitiveness across borders.
- *Sector-specific adaptations*:
    - Pulp and paper need improved heat management and recycling solutions.
    - Cement is exploring alternatives like timber and new standards.
    - Steel emphasizes recyclability and efficient material use.

Industrial Strategy and Competitiveness

To support a sustainable, competitive industrial base, Europe must focus on:

- *Strategic retention of key industries*: Europe's security of supply and competitiveness requires prioritising industries like automotive manufacturing, while recognising the need to import certain products (e.g., photovoltaic panels).
- *Primary vs. finished Goods*: The value in European production lies more in high-value goods (e.g., vehicles) than in producing all raw materials domestically.

Critical Challenges and Pathways Forward

1. *Downscaling of fossil fuels:* Oil and gas are expected to reduce significantly, while alternative feedstocks, synfuels, and electrification grow to meet energy needs.
2. *EU focus:* Discussion on critical sectors that must be retained or developed within Europe, referencing the Draghi report and NZIA (Net-Zero Industry Act).
3. *Energy Production Relocation*: Opportunities in regions with lower renewable energy costs, such as hydrogen production in North Africa, could support Europe's energy needs.

E.2.4 Key uncertainties for policymakers and for businesses of the basic industry

There is a high level of uncertainty surrounding the EU process industries' pathway to climate neutrality, as they face both uncontrollable external factors like global market shifts and controllable challenges such as technology adoption and policy frameworks.

The objective of this breakout session was to identify key uncertainties to develop resilient strategies that will guide businesses and policymakers in achieving a sustainable, competitive industrial transformation.

Key questions addressed in this breakout were:

1. What are key areas of uncertainty (technological, regulatory, financial) and what is their degree of impact?
2. What uncertainties can be influenced or controlled by EU policy or industry actions?
3. What practices can reduce the identified controllable uncertainties to support the market deployment of new, competitive products?

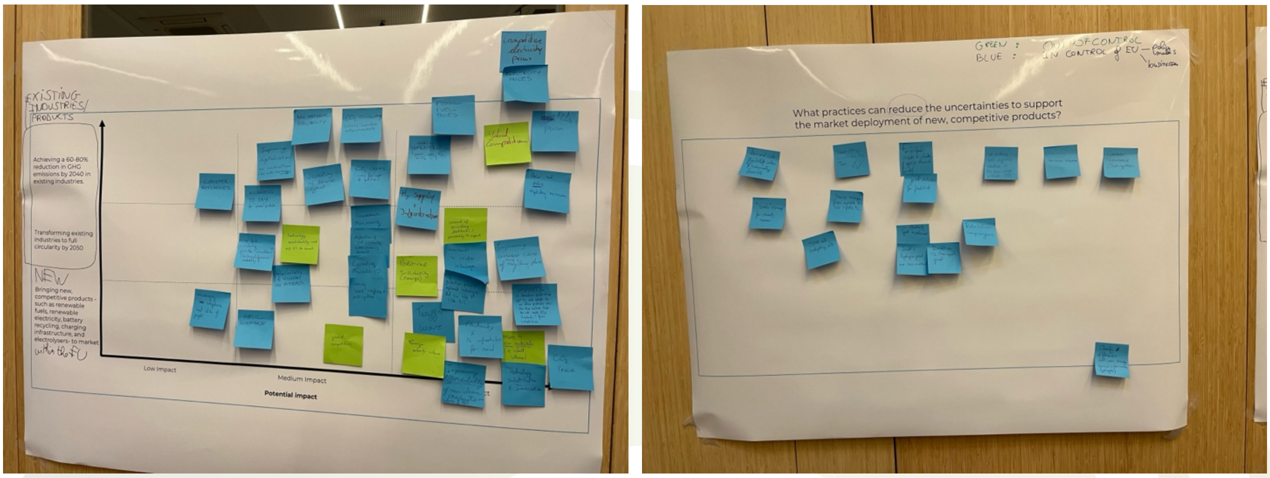

Figure 38. Photo protocol of the results of breakout 4.

Uncertainties, their potential impact and possibilities for controlling them in the EU: Decarbonising and making existing industries fully circular, as well as new industries

- **Objective**: Using these uncertainties for scenario definition
- From steel industry perspective (only industry representative in first round): Infrastructure availability and product imports ("protecting" European markets against products that do not fulfil same standards)
- New industries:
    - Uncertain demand for new technologies even if there is public commitment while production can be scaled up quickly (example of German heat pump industry)
    - Affordability might limit the demand for new technologies?
- Existing industries:
    - Technology availability and cost – Is it really out of control? Can be affected to some extent

by policies (e.g. subsidies, innovation support)
    - Global competition – Can this also be affected to some extent by limiting imports? Still not reducing cost of "local" production, mentioned for existing and new industries
    - Political instability – Affected by EU to some extent
- Uncertainty of regulatory measures (in control): Longevity and stability of policy measures at the MS level, putting EU expectations into local practice - Is it really high impact?
- Several uncertainties addressing awareness/acceptance with different impact depending on decarbonisation, circular economy and emerging technologies
- Not considering low impact uncertainties for scenario definition?

Adding new and re-allocating the identified uncertainties

- Summary of first round:
    - First round identified several high impact uncertainties and less low and medium impact uncertainties
    - First round identified mostly uncertainties, which are in control within the EU, however, some aspects are out of control, e.g. global competition, technologies, raw materials
    - Most uncertainties revolve around costs, infrastructure, consumers
- Changes compared to first round:
    - Raw material availability is partly in control within the EU, mining raw materials and using them more efficiently in the EU is possible, (probably) not enough to cover the demand
    - Electricity and CO2 prices are an uncertainty for new and existing industries, particularly decarbonisation and less circular economy
    - Public acceptance/ willingness to change is only low impact because it depends on costs/subsidies, infrastructure availability and technologies (e.g. wind), it follows from the other uncertainties and can be "easily" reduced?
- Addition compared to first round:
    - Foreign subsidy schemes outside Europe have high impact on global competition, out of control within EU
    - Coherence in EU legislation, slightly different definitions and requirements
- Practices to reduce uncertainties, especially for new industries
    - Contrast between energy supply needed for emerging technologies and emerging technologies needed for energy supply

Synthesis and prioritisation

- Identifying uncertainties achieving decarbonisation, circularity and market access for emerging technologies

  - Existing industries: Global competition, political stability, raw materials and technologies out of control within the EU, several aspects under control within EU
  - New industries: Global competition out of control, while costs and infrastructure can be affected, which again affect public acceptance
- Addressing the uncertainties for new industries: Investments in infrastructure, prioritize energy carriers, promoting collaboration