Industrial Symbiosis^2 Hubs 4 Circularity

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Abstract

This deliverable D3.2 examines the non-technological factors that are crucial for the successful implementation of Hubs4Circularity (H4C). While technological innovations play an important role, economic, regulatory, organisational and societal aspects significantly influence the feasibility and scalability of industrial symbiosis and circular economy.

A central element of this deliverable is the developed framework, which is based on a systematic literature review. This framework categorises the non-technological factors into the following main dimensions: economy and markets, regional development and (inter-)organisational collaboration, regulatory and political framework, environmental effects, and the societal dimension – benefits and challenges. These categories enable a structured analysis of the challenges and opportunities in the hubs studied.

The analysis of the four hubs – Germany, the Netherlands, and the Basque Country, and Turkey – shows significant differences in the non-technological challenges. These include regulatory uncertainties, high investment costs, social acceptance issues and insufficient coordination between stakeholders. The results of this deliverable provide a basis for future discussions and developments in the field of industrial circular economy and H4C in particular. The establishment of **Living Labs** is seen as an approach to further address key non-technological issues and develop solutions.

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List of Abbreviations

AD	Anaerobic digestion
AKKL	Arbeitskreis klimaneutrale Luftfahrt
BH2C	Basque Hydrogen Corridor
BIH4C	Basque Industrial Hub for Circularity
CAPEX	Capital expenditure
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilisation
CE	Circular Economy
CEF	Circle Economy Foundation
CENA	Centre of Competence for Climate, Environment and Noise Protection in Aviation Combined Heat and Power
CHP	Combined heat and power
CJI	Circular Jobs Initiative
CO_2	Carbon dioxide
CSRD	Corporate Sustainability Reporting Directive
DAC	Direct Air Capture
EC	European Commission
EGD	European Green Deal
EIPs	Eco-Industrial Parks
ETS	Emissions Trading Scheme
EU	European Union
FTE	Full-time equivalents
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
H_2	Hydrogen
H4C	Hubs for Circularity
IS	Industrial Symbiosis
IS2H4C	Industrial Symbiosis to Hubs for Circularity
I-US	Industrial-Urban Symbiosis
IZKA	Izmir Development Agency
km^2	Square kilometres
NGOs	Non-governmental organisation
NIMBY	Not in my backyard
NIPU	non-isocyanate polyurethane
NZBISC	Net-Zero Basque Industrial SuperCluster

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OECD	Organisation for Economic Cooperation and Development
OPEX	Operational expenditure
P4P	Processes for Planet
PED	Positive Energy District
PESTLE	Political, Economic, Social, Technological, Legal and Environmental factors
PtG	Power to gas
PtL	Power to liquid
PtX	Power to x
R&D	Research & Development
ReFuelEU	Regulation on ensuring a level playing field for sustainable air transport
SAF	Sustainable aviation fuels
SAIS	Skills Alliance for Industrial Symbiosis
SBS	Spouted Bed Solutions
SLR	Systematic Literature Review
SMEs	Small and medium-sized enterprises
SRIA	Strategic Research and Innovation Agenda
SWOT	Strengths, Weaknesses, Opportunities and Threats
TRL	Technology Readiness Levels
TUDO	TU Dortmund University
UN	United Nations
WEF	World Economic Forum
WP	Work Package

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1. Introduction

"All the innovations outlined in this chapter [of the SRIA of Processes4Planet] will only be successful if technological innovations are supported in their deployment by non-technological elements (such as skills, societal acceptance, and market conditions" (A.SPIRE, 2021).

This report looks at the role of non-technological aspects in the successful deployment of Hubs4Circularity (H4C). According to the above-cited Strategic Research and Innovation Agenda (SRIA) of Processes4Planet, it is recognised that technological innovation can deliver much more impact if non-technological aspects are properly considered and addressed. Therefore, the relevant non-technological aspects must be identified, assessed, and addressed. This is subject of this deliverable and the underlying task 3.2.

This report draws upon the stakeholder mapping already presented in Deliverable 3.1 (TUDO et al., 2025). There, it was explained that the cooperation of a large number of stakeholders is necessary to make H4C successful. These stakeholders are characterised by the fact that they contribute a wide variety of resources to H4C – both tangible and intangible. In addition to the supply of by-products, waste and energy, there are stakeholders who provide the necessary technological solutions. There is also a range of non-technological resources that are required by the stakeholders: regulatory framework conditions and approvals by public authorities, financial resources, social acceptance, skilled employees, and others. To ensure that the requirements and contributions of all relevant stakeholders are considered, the stakeholder system from Deliverable 3.1 was used as a basis so that all important non-technical aspects are covered.

In order to systematically consider these non-technological aspects in the project, the methodology for non-technological aspects described below was developed and implemented. It comprises three steps:

1. *Identification:* Relevant non-technological aspects were identified by means of literature and internet research and stakeholder surveys (questionnaire, expert interviews);
2. *Assessment:* In an evaluation of the questionnaire and the interviews, the non-technological aspects were assessed to determine which were rated as particularly important by the stakeholders. The respective (non-technical) key challenges were derived for each of the four H4C analysed;
3. *Addressing:* In a next step, hub-specific living labs are implemented in which project partners and relevant stakeholders develop and address solutions for the key challenges.

This deliverable is structured as followed: After this introduction, **Section 2** is presenting the methodology how to identify, assess and address the non-technological topics of H4C. While the literature review and web research are explicitly dedicated to the identification of non-technological topics, the empirical part draws upon the interviews which have been carried out within task 3.1. Interview questions have not only been referring to the interests and relationships of stakeholders, but have also addressed the non-technological topics stakeholders consider as very relevant for the success of H4Cs. **Section 3** presents the results of the web research and literature review (academic sources, project sources, reports and websites) identifying general non-technological topics of Industrial Symbiosis (IS)[1] and H4C[2] which have been identified as very relevant (such as economic impact, regulatory uncertainties, societal and community building incl. job creation potential and inclusiveness

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[1] According to deliverable 3.1, we understand IS as a 'collective approach' (Chertow, 2000) which is based on collaboration of different actors, the 'symbiosis partners' who are directly involved in the exchange of material and energy (Hein et al., 2017), and further actors such as associations and governmental agencies. These actors who are pivotal for the success of IS (or other projects, organisations) are considered as stakeholders.

[2] "Hubs4Circularity are socio-technical ecosystems for full scale industrial symbiosis, industrial-urban symbiosis and circular economy closing energy, resource and data loops at regional scale." Hubs4Circularity Community of Practice (n. d.)

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etc.). According to these dimensions of non-technological topics, the relevant ones for each hub are presented in detail in **Section 4**. In addition to the identification of relevant topics, those that were assessed as key challenges on the basis of the stakeholder interviews were also identified. The final **Section 5** summarises the essential content of the hub-specific key challenges and provides an outlook on how these will be addressed as subject of the Living Labs.

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2. Methodology

2.1 Literature review & web research

Various methods were used to identify relevant literature: (1) a systematic literature review of academic sources was carried out, (2) a database of H4C-relevant project reports was scanned, and (3), additional resources were identified that were needed for specific questions.

The **Systematic Literature Review (SLR)** methodology was used in this study because of its structured and thorough approach to analysing existing literature, which allows for a comprehensive understanding of interconnected concepts (Rocco et al., 2023). Prior to initiating the SLR, we examined various terms and frameworks related to H4C to refine the selection of keywords. The SLR process was conducted in four stages: (1) data collection; (2) data filtration; (3) descriptive analysis; and (4) content analysis. To ensure broad coverage, the Scopus database was chosen, as it includes a wider range of journals compared to other databases for articles published since 1996 (Chadegani et al., 2013; Falagas et al., 2008), aligning well with the study's scope.

For data collection, the following search query was applied in Scopus:

"TITLE-ABS-KEY(“stakeholder") AND TITLE-ABS-KEY(“circular economy" OR “sustainability" OR “sustainable") AND TITLE-ABS-KEY(“industrial symbiosis" OR “hubs for circularity" OR “eco industrial park" OR “eco-industrial park" OR “urban symbiosis" OR “production network" OR “industrial cluster" OR “circular hub" OR “circular* ecosystem" OR “by-product-synergy" OR “island* of sustainability" OR “positive energy district*" OR “zero waste hub*" OR “industrial recycling network*")"**.*

This query identified 234 documents. After applying inclusion and exclusion criteria – limiting results to English-language publications, focusing on articles and review articles, and restricting the scope to meso- and macro-level studies – the dataset was narrowed down to 84 documents.

Then, further documents were used to extend this research. The H4C community of practice platform[3] includes a **knowledge database** with resources from projects covering the topics circularity and industrial parks. At the time of the analysis, 133 resources were available for further analysis. For each of these resources it was checked whether they covered a range of non-technological issues, such as business, environment, regulatory, politics/policy, ethics, and society.

In addition to these two approaches, **individual documents** were also included where a topic needed to be explored in depth.

2.2 Interviews[4]

In the course of task 3.1, semi-structured expert interviews were conducted with representatives of stakeholder organisations in all four IS2H4C hubs. The interviews aimed to explore the relationships and interests of the stakeholders, as well as their perspectives on non-technological topics influencing the H4C success. For this deliverable these statements were of particular relevance.

The interviews were conducted between 01.11.2024 and 31.01.2025. Each of them lasted between 45 and 90 minutes. Interviewers used an interview guideline standardised across all hubs that covered all relevant topics and used a pre-developed analysis scheme that was intended to capture those topics in an efficient and targeted way. Then, the interview data was examined in the form of a thematic analysis. Interviewers also filled in evaluation forms for each interview to systematise the results.

The interview partners were chosen based on their relevance and influence within their H4C. In addition to the IS2H4C partners, other relevant interview partners and contact persons were identified using a

[3] See https://www.h4c-community.eu/

[4] This section is partially based on Section 2.2 of Deliverable 3.1 (TUDO et al., 2025)

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snowball system while at the same time considering the coverage of the H4C stakeholder categories[5]. The H4C stakeholder typology was provided to guide this process, and all stakeholders were asked about additional relevant stakeholders. A snowball system with simultaneous consideration of the coverage of stakeholder categories.

In total, 26 interviews were conducted with stakeholders from all four stakeholder categories: Industry, Policy, Civil Society and Academia (see Table 3).[6]

Table 3: Conducted interviews with stakeholders

Interviewed Stakeholder	Type of Stakeholder	Hub	Date of Interview
B-I1	Industry – Specific Industry	Basque hub	13 November 2024
B-A1	Academia – Technology centre	Basque hub	13 November 2024
B-P1	Policy – Public Agency (Policy Body)	Basque hub	15 November 2024
B-I2	Industry – Association of Steelworks (Services and management stakeholder)	Basque Hub	15 November 2024
B-I3	Industry – Association of specific industries, services and development stakeholders	Basque hub	19 November 2024
B-I4-A	Industry – Association of specific industries, services and development stakeholders	Basque hub	21 November 2024
B-I5	Industry – Association of specific industries, services and development stakeholders	Basque hub	26 November 2024
B-P2	Policy – Public Agency (Policy Body)	Basque hub	26 November 2024
NL-S1-A	Society – Community, local energy cooperation, non-profit	Dutch hub	6 November 2024
NL-I1	Industry – Services	Dutch hub	13 November 2024
NL-A1	Academia – Technology and Innovation	Dutch hub	21 November 2024
NL-I2	Industry – Specific industry (group of companies)	Dutch hub	26 November 2024
NL-I3	Industry – Specific industry	Dutch hub	4 December 2024
NL-I4	Industry – Specific industry	Dutch hub	12 December 2024
DE-I1-A	Industry – Services and management & specific industry	German Hub	7 November 2024
DE-P1	Policy – state-owned competence centre	German Hub	8 November 2024
DE-A1	Academia – Research and Education (Technology and Innovation)	German Hub	19 December 2024
DE-C1	Civil Society – NGO & Advocacy	German Hub	14 November 2024
DE-I2	Industry – Specific industry	German Hub	15 November 2024
DE-A2	Academia – Research and Education (Technology and Innovation)	German Hub	18 November 2024
DE-C2	Civil Society – NGO & Advocacy	German Hub	19 December 2024
DE-I3	Industry – Labor related stakeholder	German Hub	31 January 2025
TU-I1	Industry – Specific Industry	Turkish hub	15 November 2024

[5] Stakeholders were categorised into the general categories of 'Industry', 'Academia', 'Policy' and 'Society' (cf. Tleuken et al. in press). A detailed overview on the categorisation can be found in Annex A.

[6] In the text, the abbreviations in the first column in Tables 3 and 4 are used to anonymise interview data. However, general statements about hub members that do not confidential are not anonymised.

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TU-P1	Policy – Economic development Agency	Turkish hub	15 November 2024
TU-I2	Industry – Specific Industry	Turkish hub	22 November 2024
TU-I3	Industry – Specific Industry	Turkish hub	29 November 2024

2.3 Analysis of job creation and new skills

As part of the research into non-technological topics of the IS2H4C project, a baseline employment assessment for each of the hubs is conducted. This consists of analysing direct job creation potential as a result of the to-be-demonstrated synergies in each of the hubs, including the potential for inclusive job creation, and monitor the creation of jobs throughout the project.

For this purpose, a mixed-methods approach was developed to collect quantitative employment data - starting towards the end of 2024, and repeating this by the end of 2025, 2026 and 2027. Through re-circulating the jobs baseline inventory sheets by the end of these years, the research team will monitor changes in employment over time and progress towards reaching the IS2H4C's goal of creating 40,000 jobs by 2027.

The primary research question of this subtask is: "What range of employment and skills is currently associated with the hubs and how might this change by 2027?".

To answer this question, the boundaries of the employment analysis are first mapped. This activity forms the first part of the methodology: Circle Economy has mapped the solution-related node (i.e., to-be-demonstrated synergy) of the value chain that will be the focus of the employment analysis. This has been done through interviews with the hub leaders in late December 2024 (see Table 4).

Table 4: Conducted interviews for the Job creation analysis.

Interviewed Stakeholder	Type of Stakeholder	Hub	Date of Interview
DE-I1-B	Industry – Services and management & specific industry	German Hub	5 December 2024
TU-I2	Industry – Specific Industry	Turkish Hub	3 December 2024
TU-I3	Industry – Association of specific industries, services and development stakeholders	Turkish Hub	19 December 2024
B-I4-B	Industry – Specific Industry	Basque Hub	4 December 2024
NL-S1-B	Industry – Specific Industry	Dutch Hub	3 December 2024
NL-I5	Industry – Specific Industry	Dutch Hub	16 December 2024

These interviews have also been used to identify stakeholders relevant to engage in understanding changes in employment and an initial mapping of key occupations, and role and skills profiles. In summary, the topics discussed in the interviews are:

- What activities and/or processes are the most relevant to study within the hubs?
- What are the most important actors associated with these activities/processes and are, as a result, in scope for the employment baseline?
- Where in the hub will the most significant change in jobs (profile / skills) happen? For instance, where should the employment baseline be focused on?
- To fully monitor the anticipated baseline and changes in employment, is it advised to go beyond the boundaries of the hub (suppliers/service providers at the meso layer) or focus on direct employees of the companies within the hubs (micro) – or both?

This mapping of the most relevant to-be-demonstrated synergies and stakeholders is validated with the hubs afterwards, giving the hubs' representatives the opportunity to give their written feedback before

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continuing with the second step of the methodology: collecting quantitative and qualitative data for the baseline analysis.

The mapping of the analysis' boundaries is used to develop a data collection template, which collects quantitative and qualitative data for the baseline analysis, as well as the estimate of job creation and initial insights into the potential to create jobs for disadvantaged groups. The inventory sheet will cover factors including number of full-time equivalents (FTE) connected to the to-be-demonstrated synergies of focus, job profiles, skills profiles, future human capital demand, and current provision of or potential to provide employment opportunities for disadvantaged groups. This data collection template will be used to collect data from each hub in the form of a survey, which will be analysed by the Circle Economy team and then validated through interviews with the hub stakeholders. The hub leaders of each hub will facilitate distributing the survey among the selected stakeholders. By the end of the years 2025, 2026 and 2027, this exercise will be repeated in order to be able to monitor progress in terms of job creation in each of the hubs.

As a third methodological step, additional research will be conducted into the provision of jobs for disadvantaged groups. This research will be done through desk research and conducting interviews with selected stakeholders of each hub who will be identified on the basis of their insights related to the topic. These interviews, to-be conducted between February and March 2025, have the goal to identify current potential for jobs to be made available to disadvantaged groups, using an OECD categorisation (OECD, 2020). This potential will be estimated qualitatively. If the potential for inclusion of disadvantaged groups considered low (compared to the expectations of the identified stakeholders), recommendations will be developed for how new jobs could be more inclusive for these groups through consultation with stakeholders from the hubs and additional desk research. These insights and recommendations will be presented at a project meeting in a presentation to the wider research group. The re-circulated inventory sheets include data collection fields on the topic of jobs for disadvantaged groups, which will allow to monitor whether the recommendations are implemented by the hubs.

Both for the baseline analysis as well as for the research into the potential for jobs to be made available to disadvantaged groups, the data collection process is – at the time of writing this deliverable – still ongoing. Therefore, the results presented in this deliverable provide only a partial synthesis of the results currently collected. This included the identified key synergies and main identified hub-specific challenges related to employment. These results will be expanded and completed in the separate reports of (1) the baseline jobs analysis and (2) the insights from the potential job creation for disadvantaged groups analysis.

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3. Non-technological issues relevant to IS and H4C

This section delves into non-technological topics that have to be considered for the implementation of H4C. Based on the literature review and web research (see Section 2.1) they were analysed and structured using the following categorisation (see Figure 1): *Economy and markets* (Section 3.1), *Regional development and (inter-)organisational collaboration* (Section 3.2), *Regulatory and political framework* (Section 3.3), *Environmental effects* (Section 3.4), and *Societal dimension – benefits and challenges* (Section 3.5).

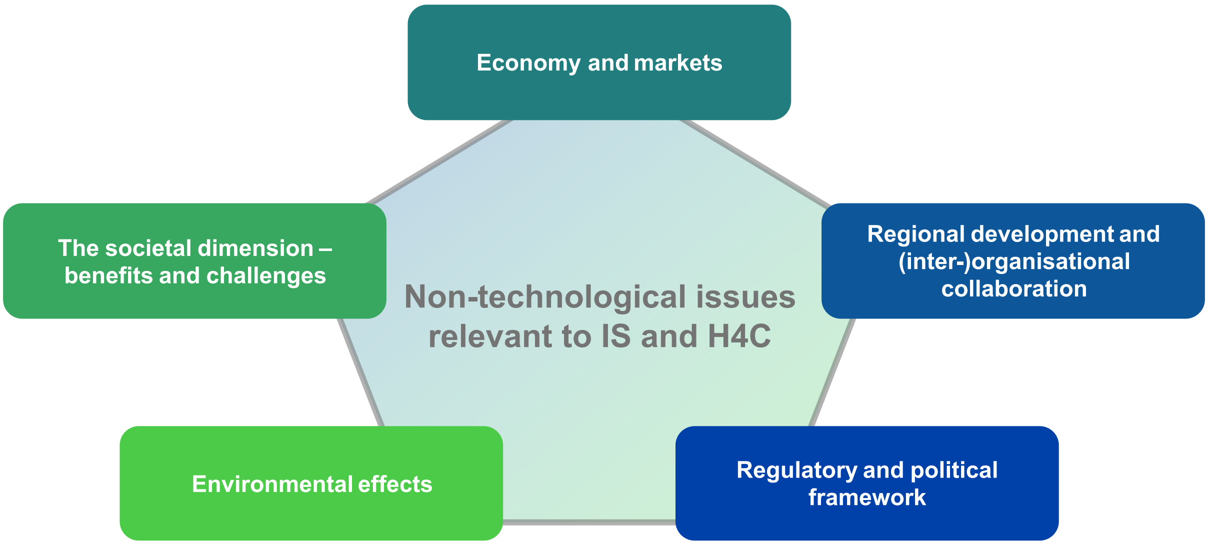

Figure 1: Non-technological issues relevant to IS and H4C

This decision for the categorisation is grounded in the integration of several established frameworks. Primarily, it is based on the framework for Eco-Industrial Parks (EIPs) developed by the United Nations (UN), World Bank, and The Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ), which outline the following categories: regulatory, technological & socio-economic, institutional & organisational (Tas et al., 2021). Furthermore, spatial considerations are particularly relevant for the H4C concept due to their regional context (Taddeo et al., 2017). Other scholars also categorise IS frameworks into similar categories, including socio-economic, technical, regulatory, and institutional (Diaz et al., 2024; Fraccascia et al., 2021; Garner & Keoleian, 1995). This categorisation is also closely aligned with the PESTLE (political, economic, sociological, technological, legal, and environmental) framework (Rastogi & Trivedi, 2016), but it is extended to include additional perspectives relevant to the H4C context.

3.1 Economy and markets

Economic viability is evaluated as one of the most important critical success factors of IS (Y. Li & Pinto, 2021). Economic benefits are a key motivating factor for engagement in Circular Economy (CE) initiatives. Raw material, energy, processing, and logistics costs must be economically viable to get companies engaged in IS (Y. Li & Pinto, 2021). According to Rentería Núñez and Perez-Castillo (2023), IS generates economic returns and competitive advantages. Simões and Vaz Júnior (2024) consider IS as an approach to gain benefits by **collaborative efforts of different companies**, in terms of cost reduction in raw materials and improved resource efficiency. **Cost savings** contribute to the resilience and self-sufficiency of IS networks, reducing dependence on energy imports and enhancing national energy security (Cawley, 2017; Ferreira et al., 2023; Filimonau & Ermolaev, 2022; Hearn & Castaño-Rosa, 2021; Martin & Harris, 2018; Yu et al., 2015). However, to achieve economic advantages in terms of long-term operational stability and efficiency, the availability of affordable and reliable energy sources is needed (Atanasovska et al., 2022; Boom Cárcamo & Peñabaena-Niebles, 2022; Civiero et al., 2021; Hearn & Castaño-Rosa, 2021; Mihailova et al., 2022; Muzamwese, 2016; Zapata Riveros et al., 2024).

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Besides cost reduction, IS can lead to additional revenues from the sale of by-products that were previously treated as waste (Neves et al., 2019). However, this presupposes that there is a market for these by-products and that customers are prepared to buy products made from recycled materials instead of virgin materials. This is related to the price of circular products and the willingness to pay higher prices (if this is the case).

Rentería Núñez and Perez-Castillo (2023) suggested that IS has proved its potential to generate competitive advantage, however, it is associated with a high level of complexity during implementation, measured in terms of the time required and the costs for long-term development. The complexity and related costs of implementing IS can hinder its adoption.

Therefore, it has to be differentiated which synergies create economic benefits and which not. While Neves et al. (2019) present a number of IS cases which have achieved cost reductions and other benefits, they have to admit that not all cases of IS can provide economic benefits to all partners. For instance, the **economic viability of waste treatment technologies** is a key factor, as the costs of recovering and utilising waste often exceed the potential financial returns (Afshari et al., 2018; Diaz et al., 2024; Ferreira et al., 2023; Guo et al., 2016; H. Li et al., 2015; Martin & Harris, 2018; Mauthoor, 2017). **Balancing sustainability objectives with financial feasibility** remains a challenge, particularly in IS systems where **long-term profitability is a critical concern** (Ren et al., 2016). Additionally, infrastructure investments, such as energy retrofitting in heritage sites, add to the financial complexity of adopting sustainable practices (Civiero et al., 2024). Potential high investments in technology and infrastructure can be an additional barrier. These investments need to be justified by corresponding economic benefits and a manageable amortisation period. The price of local and environmentally responsible products further shapes decision-making, as these options may be costlier than conventional alternatives (Cáceres et al., 2022; Rosado & Kalmykova, 2019).

Two examples may illustrate how diverse and complex the economic effects of IS can be: one is the frequently cited example of Kalundborg in Denmark; the other is Industriepark Höchst in Germany, which is analysed in more detail in Section 4.1.

The **Kalundborg Industrial Park in Denmark**, which is widely known for IS, also has a history of economic benefits from the utilisation of synergies. However, the direct economic benefit depends on the value of the by-products (e.g., due to higher energy content). While the exchange of steam for instance creates direct economic benefits, the substitution of ground water by surface water offers indirect economic benefits based on long-term strategic planning, such as supply security and expansion of production without facing obstacles of water shortages (Jacobsen, 2006).

The example of **Industriepark Höchst** shows that IS has already a long tradition in the chemical industry. Industriepark Höchst has been realising synergies in which waste, by-products or process gases are used to manufacture other products for 150 years. One interviewee (DE-I1-A) stated that the chemical industry has its origins in this – that chemical raw materials could already be obtained from the processing of tar, from which colours were initially produced. Utilising these synergies reduced manufacturing costs, which enabled lower product prices (DE-I1-A). Economic viability has therefore been the starting point of IS in the chemical industry.

However, this experience from the past cannot simply be transferred to the synergies that are to be realised as part of the IS2H4C project. The synergies envisaged by climate protection targets are often based on the use of hydrogen to replace fossil fuels such as natural gas. However, initial estimates in the four hubs analysed show that the current costs for hydrogen are around 6 to 7 times higher than those for natural gas. However, the production of e-fuels is not only more expensive due to the use of hydrogen, but also because it is significantly more complex than the extraction and refining of fossil fuels. In this respect, experiences with the economic benefits of industrial symbiosis in the past cannot be easily transferred to the four hubs in the IS2H4C project.

In view of these challenges, most several EU projects also address the issue of economic viability, for example by identifying and describing business models (SYSTEMIC, FiberEUse, REHAP). Most commonly, the potential of such business models is highlighted, while at the same time some restrictions and challenges are mentioned as well:

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- In the SYSTEMIC project, which deals with solutions for biowaste, the business cases of the five demonstration plants of the project were evaluated, including e.g., a SWOT analysis, the financial aspects, staffing, research and development, markets and marketing. The evaluated business cases generate revenues between 4.1 and 9.1 million euros (L. Hermann & Hermann, 2021). However, potential problems with the cooperation of different stakeholders regarding the sharing of profit margins are named. The establishment of "Brokers, independent companies or companies established by a group of cooperation AD [Anaerobic digestion, the authors] plants" is introduced as a possible solution, as such actors could act independently from the interests of single actors (ibid., p. 20). However, even if such a construct is established, it could still take years for it to run successfully (ibid.)
- Similarly, several demo cases that are based on the "reuse of end-of-life fibre reinforced composites" were economically evaluated with in the FiberEUse project. From the seven demo-cases that were evaluated, four were considered as profitable in each scenario, whereas there were considered as profitable only in some scenarios (Mirpourian et al., 2020). In these cases, a lower rate of recycling was considered as a safer option – highlighting that lacking economic viability might lead
- In the REHAP project a Life Cycle Costing calculation was done for the projects' solution in the area of the recycling of agroforestry waste (Leoncini & Merello, n. d.). Compared to two benchmarks, the REHAP solution was evaluated as more costly.

The SCALER project offers a standardised economic analysis of circular economy synergies in one of its deliverables (Quintana et al., 2019). The 82 analysed deliverables require investments of about 70 billion Euro in the EU and 33.5 million Euro value added.

To sum up, **economic uncertainty** is one of the most important barriers for the implementation of IS, especially, because there is a lack of quantitative information on the economic impact of its implementation in real cases" (Rentería Núñez & Perez-Castillo, 2023, p. 18). Economic viability remains a concern, with profitability often conflicting with sustainability goals (Ren et al., 2016). High initial investment, lack of financial support, and high operational costs hinder CE adoption (Bulut & Özcan, 2024; Civiero et al., 2024; Martin & Harris, 2018). Financial considerations significantly influence stakeholder collaboration, particularly when projects require substantial investments (Bulut & Özcan, 2024) and depend on external or national financial support (Asgari & Asgari, 2023; Bacudio et al., 2016; Civiero et al., 2024; Henriques et al., 2022). Consequently, Neves et al. (2019) propose economic incentives to overcome the outlined challenges.

In view of the questionable economic benefits – at least in terms of costs, competitiveness and investment – WP5 of the IS2H4C project therefore aims to analyse the question of the 'true value' of the CE in detail (see Deliverable 5.1; KPMG Portugal, 2024). The economic aspects in this deliverable 3.2 are limited to statements made by the interviewees in the four hubs that were already conducted as part of task 3.1.

3.2 Regional development and (inter-)organisational collaboration

A systemic approach that integrates multiple dimensions – such as socioeconomics, spatial dynamics, organisational capacity, regulatory frameworks, policies, environmental impacts, and community relations – should be central to **regional development strategies**. The Living Labs to be established in each Hub will help to align the different dimensions, by bringing valuable input on them and by producing valuable feedback to them: a) each (non-technological) key challenge raised by the hubs covers several of the mentioned dimensions; b) Living Lab workshops will bring together stakeholders representing different dimensions, and c) a Living Lab workshop will be dedicated to regional development strategies integrating the above mentioned dimensions. As far as available, the strategies aligned with the IS2H4C project will be cross referenced with Smart Specialisation Strategies of the involved regions.

Furthermore, these different aspects must be reflected in local and regional action plans to ensure sustainability. Spatial factors, including geography, resource availability, and specific regional

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characteristics, significantly influence the prioritisation of actions and solutions, both in the short and long term. For instance, regions facing water scarcity have different priorities than those struggling with energy supply issues. Tailoring actions to address these specific needs ensures a greater overall impact. **At the regional level**, H4C introduces specific spatial dynamics and land-use considerations that shape the physical and socioeconomic landscapes of the regions in which they operate. By co-locating diverse industries and facilitating shared infrastructure, H4C can lead to a more efficient land use and strategic clustering of enterprises that operate in an IS mode (Mortensen et al., 2023; Taddeo et al., 2012). This co-location optimises resource flows, reduces environmental impacts, and fosters collaboration among multiple stakeholders, including local communities and policy makers (Butturi & Gamberini, 2020). H4C are characterised by three main elements (Hubs4Circularity Community of Practice, 2024):

1. a structure that coordinates the activities of the **regional stakeholders**.
2. A **set of activities** that contribute to climate neutrality, CE and net zero industry.
3. A resulting measurable **impact** in terms of sustainability, economics, and environment.

It is now common knowledge and experience that the impact of CE, urban and IS practices, within industries and companies, is crucial in terms of resources and materials savings and waste management, therefore can potentially create multiple and significant economic benefits. In order to have successful implementation of CE and Industrial-Urban Symbiosis (I-US) solutions within a specific region (as CE implementation differs in each region or city, depending on geographic, environmental, economic, and social factors) the solutions should be alighted with national and regional policies (cf. ScienceDirect, n. d.), should combine true cooperation between partners, both bottom-up and top-down initiatives, the equal commitment of all stakeholders, the involvement of regional authorities that have a fundamental role in developing policies for CE transition (Arsova et al., 2022).

As identified by the research conducted in relevant H4C European Projects (IS2H4C, REDOL, THESEUS etc.) the establishment of regional H4C to a local area, can support the local ecosystem, including the local businesses, industries, citizens, associations, and authorities, by:

1. Training and capacity building of local public authorities and associations, to make them able to support and facilitate the identification and implementation of I-US synergies.
2. Providing resources for skill development and trainings to local businesses and industries.
3. Providing access to knowledge exchange, innovative solutions, novel developments, and best practices from all around the world.
4. Mobilize Researchers and Academia to try new innovative solutions to local businesses and industrial lines, creating testbeds, test new products and innovative processes. Practically, local industries have access to research and innovation activities without any cost.
5. Having access to policy making and recommendation.
6. Establish strong communication channels and long-term relationships and cooperation with local stakeholders via the H4C governance models and collaborative schemes.
7. Providing further funding schemes and mobilize external investments for the upscale of the tested solutions.

Spatial proximity among firms is a pivotal factor in IS because geographic closeness enhances the feasibility and reliability of resource exchanges (Branson, 2016). The well-known Kalundborg IS in Denmark exemplifies this, with all participants located within an eight-kilometre radius, significantly decreasing transportation costs and logistical complexities (Branson, 2016). Similar trends can be seen in Mongstad, Norway (Zhang et al., 2008), Kawasaki, Japan (van Berkel et al., 2009), and various Australian IS examples (van Beers et al., 2007). These cases highlight the importance of location-specific factors, such as transportation networks, utility availability, and proximity to raw materials or waste streams, in enhancing the operational efficiency of industrial symbiosis.

Beyond mere distance, factors like geographic range, local traffic conditions, and ***strategic infrastructure placement*** also influence efficiency and sustainability (Haller et al., 2022; Herczeg et al., 2018). Co-locating facilities minimises transportation distances, leading to lower logistical costs and reduced greenhouse gas (GHG) emissions. Early waste management planning further supports optimal spatial arrangements, demonstrating the value of integrated land-use planning (H. Li et al., 2015).

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However, spatial planning must also account for potential adverse effects, such as noise, traffic congestion, and air pollution, which could lead to negative feedback from surrounding communities. Mitigation strategies – such as buffer zones or dedicated transport corridors – can help ensure that IS hubs harmoniously coexist with nearby communities.

Regulatory and political factors (see Section 3.3 for more details) play a crucial role in shaping spatial dynamics and determining where and how H4Cs can develop (Branson, 2016). In many regions, zoning laws, building codes, and environmental regulations impose constraints that can either hinder or promote innovative IS initiatives (Butturi & Gamberini, 2020; Civiero et al., 2024). Decentralised energy production and shared infrastructure facilities can alleviate some of these constraints, making industrial clusters more spatially viable. An inclusive planning process – one that involves municipal governments, industry stakeholders, and residents – can help align H4C development with both national decarbonisation goals and regional development priorities. A multiple approach is therefore required, where CE and I-US initiatives need to be aligned with and integrated into national, regional, and local development strategies, reflecting the unique characteristics of each region. Amsterdam, Glasgow and Copenhagen are good examples of how different policy areas are being challenged and affected due to the CE strategies (Calisto Friant et al., 2023). Additionally, local authorities and policy makers play a key role in the governance of H4C by providing critical insights, prioritising issues based on regional needs, and facilitating two-way interaction between H4C and regional planning efforts. Their involvement ensures that actions, solutions, and infrastructure development are aligned with broader sustainability and economic development goals but also helps to foster readiness to buy sustainable products.

The climate adaptation and circular economy activities are involving to a crucial part of economic and social activities, and they are constantly spreading in every aspect of urban, rural, and industrial environments and related to land use, regulations, wastes, energy, water, materials, infrastructures, technologies, networks, consumer practices, etc. Therefore, H4C, following this multiple systemic approach, considering and integrating the relevant aspects (analysed also in other sections, such as the regulatory and political framework), and having in its core the resulting measurable impact in terms of sustainability, is the "bridge" between climate adaptation and CE activities and the regions, interacting both forward and backward, designing, planning, developing and integrating these activities into the regional scenery, into the development strategy and relevant development action plans, towards overall sustainability.

At the organisational level, institutional and organisational capacities are critical to advancing CE and IS. The institutional dimension examines the entities and organizations participating in the project or initiative, whereas the organisational dimension addresses the operational elements of execution, including workflows, efficiency, and logistical considerations. Institutional factors address a range of challenges, including uncertainties and risks in in passive stakeholder engagement due to inadequate planning and risk mitigation strategies (Civiero et al., 2024). Stakeholder engagement can be implemented in several steps, as shown by European examples: (a) stakeholder definition, (b) stakeholder analysis, (c) stakeholder engagement planning, (d) stakeholder engagement process, and (e) stakeholder engagement indicators (Knöbl et al., 2023).

Effective planning is essential to ensure continuity in actions (Faria et al., 2023), particularly as IS initiatives often depend on long-term commitments and cooperative networks. Organisations must develop risk mitigation frameworks to manage reliance on emerging technologies, which, while innovative, can introduce operational uncertainties (Kerdlap et al., 2019; Liu et al., 2020; Pilouk & Koottatep, 2017; Rincón-Moreno et al., 2020).

In terms of organisational capacity, resource availability is a key enabler for IS. Industries require by-products of specific quality and quantity to facilitate exchange, often requiring specialised treatments to make waste usable (Filimonau & Ermolaev, 2022; Hong & Gasparatos, 2020). This reliance on technological specificity (Herczeg et al., 2018) and the diverse composition of industrial waste (Mauthoor, 2017) pose logistical and processing challenges that institutions can help address through technical and financial support.

Coordination, development of expertise, and alignment with CE principles are critical to institutional success in promoting IS. The creation of robust inventory management systems and long-term circular

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strategies ensures that industries align their operations with sustainable practices (Hariyani & Mishra, 2024; Vanhamäki et al., 2020; Zhu et al., 2015). However, there are many challenges in solid waste management due to the lack of policies focused on sustainability, the lack of communication and trust between stakeholders, the low use of technology in the industrial sector and technical barriers (Boom Cárcamo & Peñabaena-Niebles, 2022). At the same time, however, societal acceptance is critical for coordinating multiple stakeholders and aligning their priorities and interest (see more in Section 3.5).

Clearly defining the roles, responsibilities and functions of facilitators, such as public authorities, ministries, regions and municipalities, associations, utility operators, consulting firms, research projects, research institutes etc., or a combination of these entities in a public-private partnership r (Hariyani & Mishra, 2024; Hentschel et al., 2018; Pietrulla, 2022). Facilitators can act as intermediaries to align different stakeholders, manage conflicts, and identify synergies. At the same time, training programmes and educational initiatives create the expertise needed to implement IS effectively (Boom Cárcamo & Peñabaena-Niebles, 2022).

Small and medium-sized enterprises (SMEs) face unique barriers, such as limited internal resources, which hinder their ability to participate in sustainable transitions (Cawley, 2017; Civiero et al., 2024; Gibbs & Deutz, 2005; Testa et al., 2017; Zhu et al., 2015). Institutions, involved in H4C, can support SMEs by facilitating access to funding, offering shared infrastructure, and enabling cooperative networks that pool resources. Addressing trust and confidentiality concerns is equally important, as these often prevent resource sharing and collaboration (Aviso et al., 2022; Bacudio et al., 2016; Civiero et al., 2021; Mauthoor, 2017). A lack of trust can stem from concerns about data security, competitive risks, and the reliability of partners within IS networks. To overcome these barriers, establishing transparent governance mechanisms and legal agreements is crucial in ensuring that intellectual property, operational data, and business-sensitive information are protected (Civiero et al., 2021; Gibbs & Deutz, 2005). Additionally, developing long-term partnerships through clear communication, joint initiatives, and pilot projects can help build confidence among stakeholders (Bacudio et al., 2016). Third-party mediators, such as industry associations or public agencies, can play a key role in facilitating collaboration by providing neutral oversight and ensuring compliance with agreed-upon frameworks (Bacudio et al., 2016; Ferreira et al., 2023). By actively addressing trust issues, SMEs can participate more effectively in CE initiatives, benefiting from shared resources while mitigating perceived risks.

3.3 Regulatory and political framework

Regulatory and political frameworks play a fundamental role in shaping IS initiative and can have both a stimulating and a counterproductive effect (see Wolkinger et al., 2019). If political initiatives or programmes are poorly coordinated between different political levels or do not exist at all, uncertainty may arise and planning may come to a standstill – in this sense, planning certainty is an important prerequisite for private investment (ibid.).

The structure and design of regulations influence the implementation of sustainable practices by establishing legal guidelines, defining compliance measures, and providing financial mechanisms that support industrial collaboration. Policies designed to promote IS include regulatory incentives such as tax reductions, interest-free loans, and funding programs that facilitate sustainable transitions (Civiero et al., 2024; Filimonau & Ermolaev, 2022; Gibbs & Deutz, 2005; Haskins, 2007; Mauthoor, 2017; Pilouk & Koottatep, 2017). In addition, the establishment of technical guidelines for waste management and industrial resource exchanges ensures that symbiotic practices operate within a structured and efficient regulatory environment (Hentschel et al., 2018; Iacondini et al., 2015). To ensure compliance and effective implementation, legal enforcement mechanisms are required, including audits and standardised regulatory oversight (Asgari & Asgari, 2023; Faria et al., 2023; Koch et al., 2022; Tröger et al., 2023; Zapata Riveros et al., 2024). These mechanisms should be optimised to avoid excessive bureaucracy while ensuring compliance, thereby streamlining processes and encouraging broader participation in IS initiatives, which is also recognised as a burden in the EU Competitiveness Compass (European Circular Economy Stakeholder Platform, 2025). Adaptive and flexible regulatory frameworks further enhance the ability of industries to integrate sustainable solutions without excessive bureaucratic constraints (Haller et al., 2022).

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Regulatory policies also influence industrial landscapes by determining how resources are managed, reused, and exchanged across sectors. In many cases, existing regulations have historically favoured linear economy models, while the absence of clear policies supporting IS has slowed the adoption of circular strategies (Afshari et al., 2018; Civiero et al., 2024; Haller et al., 2022; Kerdlap et al., 2019; Yadav & Majumdar, 2023; Zapata Riveros et al., 2024; Zucchella & Previtali, 2019). Specific policy gaps, such as the lack of guidelines on remanufacturing processes and carbon pricing, present challenges for industries seeking to transition toward circularity (Barona et al., 2023; Henriques et al., 2022; Pilouk & Koottatep, 2017). Additionally, regulatory frameworks governing the classification of waste materials, including rules on the “end-of-waste” status of products, create complexity in resource recovery processes and influence the operational feasibility of industrial symbiosis (Iacondini et al., 2015; Rosado & Kalmykova, 2019). Coordination among regulatory bodies is necessary to prevent overlapping authorities and conflicting legislation, which can complicate compliance requirements and slow down implementation efforts (Kerdlap et al., 2019). For instance, the European Union's 2020 Circular Economy Action Plan explicitly emphasises facilitating and enabling industrial symbiosis as an essential means of transforming consumption and production patterns towards greater circularity within industry (European Commission, 2020b)

The effectiveness of regulatory frameworks also depends on how well they balance enforcement and incentives. While compliance-driven policies, including audits and penalties, ensure that sustainability regulations are upheld, incentive-based mechanisms provide businesses with tangible benefits that encourage their participation in industrial symbiosis (Bulut & Özcan, 2024; Henriques et al., 2022; Mattsson et al., 2023; Stubbs, 2014). Studies highlight that a combination of strict enforcement and well-designed incentives creates a more effective regulatory environment for CE adoption (Faria et al., 2023; Fric & Rončević, 2018; Liu et al., 2020; Muzamwese et al., 2024). Financial support measures, such as subsidies and grants, provide essential resources that enable businesses to implement and sustain circular practices (Barona et al., 2023; Bulut & Özcan, 2024; Cawley, 2017; Hearn & Castaño-Rosa, 2021; Henriques et al., 2022; Yu et al., 2015). Furthermore, regulatory stability and long-term policy commitments contribute to business confidence, encouraging industries to invest in sustainable solutions without concerns over sudden regulatory shifts (Gibbs & Deutz, 2005; Henriques et al., 2022; Yu et al., 2015).

On the European level, European Commission´s policies set the framework and direction of European economic and research and development strategies. In January 2025, the European Commission published the EU Competitiveness Compass (European Commission, 2025a), based on a comprehensive report by economist Mario Draghi, known as the Draghi report. It sets out the EU’s strategy to close the innovation gap, develop competitiveness and decarbonisation jointly and reduce excessive economic dependencies. The EU Competitiveness Compass develops various initiatives that support circular economy development and industrial symbiosis in Europe. Among these initiatives, the Clean Industrial Deal aims to enhance the EU's attractiveness for manufacturing by promoting clean technologies, circular business models, and targeted state aid to accelerate decarbonisation. Similarly, the proposed Circular Economy Act encourages investments in recycling infrastructure, substitution of virgin materials, and waste reduction through eco-design requirements for key products. Further strengthening the EU's sustainability goals, the Industrial Decarbonisation Accelerator Act intends to accelerate permitting processes for sectors undergoing decarbonisation, complementing existing renewable energy and Net Zero initiatives. The Electrification Action Plan and European Grids Package will modernise Europe's energy infrastructure, supporting clean energy transitions and optimising the Single Energy Market. Concurrently, the European Biotech Act and Bioeconomy Strategy seek to solidify Europe's position in bio-based sectors, reduce fossil fuel dependency, and enhance rural economic prosperity. The Joint Purchasing Platform for Critical Raw Minerals will coordinate EU-wide demand, ensuring reliable and diversified raw material supplies crucial for sustainable sectors (European Circular Economy Stakeholder Platform, 2025).

The European Commission already had included CE into the new industrial strategy for Europe (European Commission, 2020a) and the new CE Action plan (European Commission, 2020b), both published in 2020. The transition towards more circular industrial production away from linear production is part of the strategy of the European Union (EU) to become climate neutral by the year 2050 and increase the resilience of supply chains as laid out in the European Green Deal (European

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Commission, 2019). Several specific key value chains are addressed in specific actions and several regulations aim at promoting and facilitating circular production, e.g., the directives on batteries (European Parliament & European Council, 2023) and plastics (European Commission, 2018). In parallel, the EU Taxonomy regulation (European Parliament & European Council, 2020) aims at steering financial and non-financial companies towards investing in sustainable product and company development. To do so, a regulation and further standardisation processes of what can be understood as sustainable investments is part of the EU Taxonomy policy. It sets out six environmental objectives, of which one is transition to CE (European Parliament & European Council, 2024). Recently, the European Commission presented the Clean Industrial Deal that puts decarbonisation and competitiveness as well as resilience of the European industry at the centre of the European growth strategy. CE is once again part of this strategy, with a focus on recovering critical raw materials to increase independence from materials imports. It showed the EC's plan to adopt a CE Act in 2026, create an EU Critical Raw Materials Centre for joint purchase of raw materials to increase economy of scales (European Commission, 2025b). The Clean Industrial Deal also takes up a number of topics that have been deemed relevant for the implementation of IS. An Industrial Decarbonisation bank has been proposed and several counter-guarantees by the European Investment Bank are foreseen to facilitate investments in clean technology, renewable energy, and infrastructure. The carbon accounting methodology will be simplified, energy costs will be tackled, upskilling and quality jobs are supported by the Union of Skills and new partnerships beyond Europe shall increase supply chain security and competitiveness. Additionally, bureaucratic burdens are promised to be reduced, such as the Corporate Sustainability Reporting Directive (CSRD) reporting obligations and the EU Taxonomy reporting obligations (European Commission, 2025).

According to the European policies, EC funding dedicated to research and innovation has started funding projects that develop and/or implement solutions for CE and IS at different levels such as dedicated calls in the Horizon Europe funding program, regional policy support, the LIFE programme and within the single market programme. Similarly, several European member states have developed national policies aiming at fostering CE and IS (e.g., the German CE Strategy (Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection, 2024), the Dutch National CE Programme 2023 – 2030 (Rijksoverheid, n. d.–a, Rijksoverheid, n. d.–b) and the National Strategy for the CE in Romania (Ministerul Mediului, 2022) to name just a few examples[7]).In addition to the academic discussion and according to the European policy of fostering CE, the topic of the regulatory-political framework is also being discussed in various EU projects dealing with circular solutions – mostly in the context of defining of requirements for this framework:

- Reports from EU projects on Circular Industrial Parks have dealt with various aspects of the political-regulatory framework in recent years: Deliverable 7.11 of the REMADYL project (Drost, 2019) and Deliverable 2.1 of the SYSTEMIC project (L. Hermann & Hermann, 2018) deal with the relevant standards and regulations in their respective use cases.
- Deliverable 9.3 of the polynSPIRE project and Deliverable 6.6 of the CIRC-PACK project cover legal hurdles for the recycling of plastic (CIRCE, 2022)
- The REMADYL Policy Brief (REMADYL, n. d.) as well as the joint Policy Brief of the CREATOR and REMADYL (REMADYL & CREATOR, 2023) project both include various policy recommendations.
- Deliverable 4.12 of the SYSTEMIC project (Schoumans et al., 2021) presents a roadmap that also includes a chapter on legal aspects.
- Deliverable 4.1 of the SCALER project (Vladimirova et al., 2021) presents an overall strategy and recommendations for Industrial Symbiosis and also addresses political actors.

[7] For an overview of roadmaps and action plans towards CE on the regional and national level use the European CE Stakeholder Platform website European Commission and European Economic and Social Committee (n. d.)

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- Without going into detail regarding the technical specificities and topics of the individual projects, it is possible to identify some patterns of requirements for the political-regulatory framework.

The legal regulations of the EU and its member states create a framework within which private investment should take place. As is clear from both the scientific literature (see above) and the various project deliverables, this framework has to fulfil multiple functions:

1. It should enable the **standardisation** of products and processes. Various aspects could be covered by this. The joint policy recommendations of the CREATOR and REMADYL projects, which both deal with the recycling of hazardous additives, call for a standardised definition of the recycling rate that is valid for several processes (REMADYL & CREATOR, 2023). The SYSTEMIC Deliverable (Schoumans et al., 2021) emphasises the importance of defining end-of-waste criteria. The polynSPIRE endorses a Plastic Neutral Certification (CIRCE, 2022). More generally, the SCALER deliverable (Vladimirova et al., 2021) calls for 'standardisation at all levels'.
2. Processes in connection with the authorities should be kept as lean as possible, i.e. a **reduction of bureaucracy** should take place, e.g., in relation to approval procedures (see e.g., Schoumans et al., 2021)
3. Also, some projects actively propose an active role of policy actors to **coordinate circular solutions.** For example, the SCALER project proposes that "regional/ local government and city authorities in some places can exert powerful leverage by mandating and actively managing IS activities" (Vladimirova et al., 2021)
4. Some of the project deliverables refer to conflicting objectives. In the Policy Brief of the REMADYL project (REMADYL, n. d.), "balancing the requirement of the circular economy and that of the non-toxic environment" is named as one Policy challenge. Thus, **balancing different targets**, seems to be one of the issues that needs to be considered.
5. Often, a **public funding of circular solutions** is demanded. In the REMADYL & Creator Policy Brief (REMADYL & CREATOR, 2023) it is demanded to support the price of recycled plastic to give it an advantage compared to non-recycled plastic. According to this text, this could be realised through VAT reductions, investments subsidies, a lower taxation of labour in the recycling sector or an increased CO_2 tax. In the SYSTEMIC deliverable (Schoumans et al., 2021) incentives as well as extension of the carbon credit system are demanded. The SCALER deliverable (Vladimirova et al., 2021) requests financial incentives for both the industry and the research institutes / knowledge intermediaries. The polynSPIRE project demands both to link financial subsidies to recycling standards and a system for plastic that is similar to the CO_2 emissions trading system (CIRCE, 2022).
6. In addition to such financial incentives, measures are also being discussed that set **legal limits** for the use of non-circular options or set minimum shares for circular options. In these cases, however, it is often emphasised that it is important not to set limits that are overburdening the industry. In the REMADYL and CREATOR Policy Brief the issue that is discussed is double-edged: On the one hand, mandatory recycled enhances the market demand for the products, on the other hand they emphasise that targets could also refer to areas where new limits could lead to technical and quality problems (REMADYL & CREATOR, 2023). Also, they emphasise that replacing a substance should only take place if an alternative meets certain criteria (ibid.). Comparing incentives with stricter limits, the SYSTEMIC report (Schoumans et al., 2021) proposes to use limits only if incentives prove to be ineffective.
7. Better **controlling** and **monitoring** measures are also often demanded. For example, the REMADYL & Creator Policy brief includes the recommendation to improve the "control of hazardous substances in imported products" (REMADYL & CREATOR, 2023). In a different context, the SYSTEMIC deliverable (Schoumans et al., 2021) emphasises the need of strict monitoring of used fertiliser substitutes in agriculture.
8. **Providing a stable investment ecosystem:** In addition to taking actual measures, the stability of the political and regulatory framework also plays an important role. If this stability is given (at least subjectively), it strengthens the willingness of the companies involved to invest. SCALER for example stresses the need of national agencies to "build trust among

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industries, research institutes/knowledge intermediaries and public authorities" (Vladimirova et al., 2021)

Overall, it is clear that the EU actively included CE and related strategies into their political agendas. A successful political-regulatory framework must, however, fulfil a whole range of requirements and is therefore quite difficult to shape. Sometimes these objectives differ, because greater standardisation or better controls also require more bureaucracy, for example, and conflicting interests can also arise when it comes to conflicting policy goals, such as environmental security, climate change or economic viability.

3.4 Environmental effects

A primary objective of IS and H4C is to mitigate industrial environmental impacts by reducing emissions, optimising resource use, and enhancing circularity. The different aspects of these concept affect the ecological ecosystem in the vicinity of H4C sites and beyond, including effects on global climate change (Mattila et al., 2010).

Therefore, they are strategically addressed by IS in H4C as part of the EU's strategy for decarbonisation of the industry and the European Green Deal.

The European Commission's new CE Action Plan (European Commission, 2020b) aims at:

- Reduction of energy and water consumption
- Reduction of waste production
- Reduction of GHG emissions
- Achieving the overall decarbonisation of industry
- Reduction of the need for mining or importing raw materials by cutting resource consumption

A literature review by Wadström et al. (2021) has shown that the most reported environmental outcomes of IS were related to *climate change* (effects on CO_2 and other GHG emissions), *freshwater use* and *chemical pollution and hazardous waste.* Other indicators analysed were *acidification, atmospheric aerosol loading* (effects on overall particulate concentration in the atmosphere), *land-system change* (mainly referring to the conversion of land into cropland or renaturation), *rate of biodiversity loss*, *biogeochemical flows* (referring to phosphorus and nitrogen cycles) and *ozone depletion,* in that order (Wadström et al., 2021, p. 11).

Environmental effects are also an important non-technological subject of debate between the H4C stakeholders: Policy and Civil society stakeholders such as the EC, national and regional governments, citizens, and environmental advocacy NGOs raise questions of environmental effects of H4C. While positive effects can legitimise the development of H4C and necessary infrastructure for stakeholders, such as citizens and local governments, negative effects, and additional use of land for facilities can create resistance (see Section 3.5.2 for a more detailed discussion). The expectations of positive (and negative) environmental effects of IS and H4C by regional authorities, the public or other stakeholders or that are set out in regulations, also bear significant meaning for the feasibility and support for such implementations.

Regarding **positive environmental effects**, multiple effects can be expected. Collaboration at the local level within IS can help minimise raw material consumption, emissions, and waste generation. The environmental advantages of a CE arise from lowering resource consumption (materials, energy, and water) and minimising waste and emissions: The exchange system generally transforms negative environmental externalities, primarily waste, into positive ones, such as reduced pollution and decreased demand for raw materials (Chertow & Ehrenfeld, 2012).

Through recycling, reusing, or repurposing of waste products, H4C decreases the need for virgin resources in manufacturing and other industrial sectors (Mendez Alva et al., 2021). This careful management of inputs preserves finite natural resources and helps maintain biodiversity.

A transition towards a more CE holds a vast potential for the *decarbonisation of industry and reducing GHG emissions*. Decentralised, shared utilities, co-generation of heat and power, and synergies that

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allow for hydrogen recovery, for example, contribute to industrial ecosystems that produce fewer emissions per unit of output. H4C lower GHG emissions by improving energy efficiency and encouraging the use of low-carbon energy sources (Mendez Alva et al., 2021), by heat-recovery synergies and by using GHG as feedstock for biogas or biofuels (Wadström et al., 2021). In this way, H4C should contribute to the overall societal goal of limiting climate change. Several studies have estimated the potential of CE for emissions reduction on different geographic scales: A study for the German industry estimated that 25% of emissions until 2040 could be avoided (Shawkat et al., 2023) while an estimate published by Materials Economics calculated CO_2-emissions of energy-intensive industries in the EU could be reduced by 56% until 2050 by transitioning towards CE (Material Economics, 2018). Achieving these emissions reductions will, of course, depend on a number of factors, including regulatory and policy frameworks. Policies are necessary to set targets and initiating measures to implement CE strategies. Overcoming regulatory, economic and technological barriers of upscaling and cost-effectiveness and the active pursuit of CE by both, industry and policy stakeholders, are crucial to achieve the potential beneficial environmental effects (cf. Shawkat et al., 2023, Material Economics, 2018).

Looking at the 74 of the 100 IS synergies identified in the SCALER project for which an environmental impact assessment[8] could be carried out, a potential saving of 122 million tonnes of GHG was calculated (Lessard & Laffeley, 2019) – as much as three to four percent of the total GHG emissions in the EU in 2022. Also, many of the other relevant EU projects cover the reduction of GHG emissions in their life cycle assessment reports:

- In the ZERO BRINE (see Harris et al., 2022) project a new process of recovering wastewater streams is developed and tested. This new system not only consumes less energy but also increases the recovery of two chemicals (sodium chloride, and magnesium hydroxide). Both measures also reduce the GHG emissions: Compared to a reference system, the new system emits around a third less GHG emissions.
- The SYSTEMIC project (see R. Hermann et al., 2022) deals with the recovery and recycling of nutrients in biowaste. In five demonstrations plants, the GHG emissions are reduced between 0.7 and 22 percent, which highlights the dependency of actual reductions on local configurations.
- The SuSPIRE project (see Cerrillo & Mendoza, 2019) focuses on different technologies that help to efficiently capture and reuse stored thermal energy (p. 4) in energy-intensive industries. Comparing this new process to the current process, a reduction of GHG emissions of 22 percent was detected (p. 15).
- In the course of the REMADYL project (see Caro et al., 2023) the impact of adding chemical recycling methods of plastic to existing mechanical recycling is estimated. GHG emissions are expected to decline by about 3.7 percent (p. 68).

Water consumption and wastewater discharge can be significantly optimised in H4C (and in general in IS initiatives) (Mendez Alva et al., 2021). By capturing and repurposing water streams within the hub, industrial facilities reduce the strain on local water supplies and minimise the release of pollutants (Mendez Alva et al., 2021; Wadström et al., 2021). The SCALER project found that implementing the 38 most influential synergies would save 2.5 billion cubic metres of water (Quintana et al., 2020). This corresponds to around 1.3 percent of the annual freshwater abstraction in the EU in 2022 (European Environment Agency, 2024).The *reduction of materials consumption* also has positive environmental effects, as it reduces the need for additional mining and quarrying and landfill, which in turn can reduce land system change, earth and water pollution and freshwater usage. IS systems that focus on material recovery and material flow loops can avoid demand of materials, such as aluminium oxide recovery

[8] The SCALER project made use of the lifecycle assessment approach that is widely adopted for the impact measurement of products over their lifetime. It is based on similar impacts like the one reported on in the literature review presented by Wadström et al. (2021) and takes into account materials, energy, and resources used in production and use of the product as well as the impact at the end of a product's life, such as landfill, incineration or hazardous waste production (or types of recycling). For details on the approach applied in the SCALER project see Lessard and Laffeley (2019).

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from salt slag of non-ferrous metals industries that is used in the cement sector, with a CO_2-equivalent reduction between 3.5 and 5 thousand tonnes of CO_2-equivalents per year, resulting from the avoided aluminium oxide production and the avoided slag landfilling (Lessard & Laffeley, 2019, pp. 27–28). Similarly, the *reduction of solid waste in landfills and of hazardous matter* in waste reduces acidification and the chemical pollution of earth and water as well as the limits the land needed for landfill and safe storage of hazardous waste. These developments can have the effect of decreasing the rate of loss of biodiversity as land system-change is the most influential factor for it (Wadström et al., 2021).

At the same time, the implementation of IS can also have **negative environmental effects**. Processes used in IS most often need (additional) energy as input. For some types of IS, dedicated additional tools and machinery are constructed and need electricity to function, which in turn adds to energy and materials demand. Some IS systems also need additional resources for the key processes to be productive, such as water, hydrogen, or other materials and thus also add to resource demand. Additionally, transport is one of the major counteracting factors for the decarbonisation effects of IS at the moment (Harfeldt-Berg, 2024; Marcinkowski, 2019), as some major transport routes, such as lorries, are powered by fossil fuels (Lessard & Laffeley, 2019) and relevant infrastructure, such as piping or storage, is yet to be constructed. Another counteracting factor is additional land needed for infrastructure or new facilities. Here, the effect on biodiversity and other functions of land-system change need to be considered.

Overall, IS can have positive and negative environmental effects at the same time (Wadström et al., 2021) and, depending on the regional conditions, different environmental effects have different relevance, impact and urgency. This is why for each H4C and each IS the topic of environmental effects can be an issue that needs to be addressed among stakeholders and has thus the potential to facilitate or hinder the development of the H4C. Particularly, the work of the SCALER project is of relevance with regards to understanding combined positive and negative environmental effects of IS. The project employs an approach to map both, positive and negative environmental effects of IS implementations, and calculating net effects on different indicators: One hundred synergies were identified that are intersectoral, thus cover different industry sectors (Azevedo et al., 2019, p. 6). Within SCALER's report of its Deliverable 3.3 the environmental impact of these synergies has been assessed (Lessard & Laffeley, 2019), estimating a baseline scenario without the synergy and a scenario implementing the synergy, calculating the effect on climate change, human health, ecosystem quality, and resources depletion of each synergy. This approach can add to the understanding of environmental impacts of H4C and make effects more transparent towards civil society and policymakers, facilitating conducting dialogue and finding solutions that benefit all stakeholders.

3.5 The societal dimension – benefits and challenges

A growing field of study takes a critical perspective on the CE and its societal contribution potential (Calisto Friant et al., 2020). Scholars argue that current CE activities and policies prioritise environmental goals and are focused on a technocratic agenda that develops strategies for industry and products. This causes certain social considerations to be neglected. Therefore, consideration of possible societal resistance and social benefits should be included in the initial project conception and management of H4C and IS processes, and appropriate relationships between stakeholders from industry, society and politics should be the goal, going hand in hand with behavioural changes. In addition, to better understand the employment potential of the CE, policy makers, industry decision makers and other stakeholders need concrete evidence on how jobs will change and how can this be adapted. Specifically, projects can focus on integrating societal values with CE principles, building inter-stakeholder trust, addressing social factors, optimising stakeholder coordination, enhancing stakeholder communication, ensuring collaborative engagement, raising stakeholder awareness, exhibiting leadership commitment to CE, ensuring access to quality information, and developing specialised expertise (Tleuken et al., in press). Detailed methodologies and quantification strategies for these indicators will be clarified in D3.3.

Societal issues are often equated with societal resistance). "Not in my backyard“ (NIMBY) is a phenomenon mentioned by companies and associations when it comes to the societal aspects of H4C (see van der Horst, 2007; Wexler, 1996). Social acceptance of new infrastructure (such as hydrogen or

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CO_2 pipelines) or acceptance of circular products (often linked with higher prices) represent societal challenges for the implementation of H4C. They are more extensively described in Section 3.5.2.

While societal benefits are often equated with environmental benefits (see Section 3.4), there are also societal benefits in their own right, such as job creation and inclusiveness which are often overlooked in the discussion of societal issues. This is in line with Calisto Friant et al. (2020) who note that the social dimension in the CE is often neglected.

The underestimation of the social dimension of IS/H4Cs may also be related to a lack of sufficient knowledge about the social impacts of the IS practice, as reported by Wadström et al. (2021). Therefore, relevant aspects of the social dimension are presented here in order to better understand the social dimension of IS in this project and its links with other dimensions. Hub-specific challenges in Section 4 provide project-specific examples of social dimensions in the H4C.

The social outcomes of IS can be seen in particular in those aspects that create social value and benefits for society (Wadström et al., 2021, p. 8). However, in the various processes of IS, there are **not only social benefits, but also challenges** to society and community relations.

3.5.1 Benefits

In addition to the environmental benefits described in Section 3.4, the creation of new jobs, inclusiveness of disadvantaged people at the labour market, and the improvement of local skills are important benefits of IS (Martin & Harris, 2018). The **creation of new jobs** in the CE is considered as one of the most important societal benefits. At least, the adoption of CE strategies within industries such as IS will result in changes in the labour market. While such employment impacts are often neglected, early estimates are encouraging. The International Labour Organization (ILO) estimates that a net total of seven to eight million new jobs will be created globally by 2030, as a result of policies and changes associated with the circular economy (International Labour Organization, 2018). Also, in the IS2H4C project, a substantial increase of circular jobs is estimated as soon as the implementation of H4C is successful (using a broader range of potential synergies). This is all the more important as the high energy prices in Europe pose a significant challenge to the competitiveness of (energy-intensive) companies – with the potential for jobs losses as plants are relocated elsewhere in the world.

To better understand the employment potential of the CE, policymakers, industry decision-makers and other stakeholders need evidence on how jobs will change, in which economic sectors these changes will occur, and what the necessary skills profiles for circular jobs will be.

The CE is an evolving concept that has until now been defined and measured in various ways, which is reflected in the diversity of understandings of its associated employment implications (Circle Economy et al., 2024). The Circular Jobs Initiative (CJI) at Circle Economy defines a circular job as “any occupation that directly involves or indirectly supports one of the strategies of the circular economy” (Circle Economy & Goldschmeding Foundation, 2021). It then identifies three types of circular jobs: (1) core circular jobs: all jobs that ensure the closure of raw material cycles, such as jobs in repair and waste- and resource management. (2) enabling circular jobs: jobs that remove barriers to and enable the acceleration and upscaling of core circular activities, such as jobs in e.g., leasing and design, and (3) indirectly circular jobs: jobs that indirectly uphold the CE and occur in other sectors that do not play a direct role in furthering the transition to the circular economy but can still adopt circular strategies. They include jobs that provide services to core circular strategies.

However, to unfold the potential of new jobs, it needs to be analysed which skills requirements are linked with the new jobs. Only when potential employees have developed these required skills can the potential jobs be filled with suitable candidates.

A circular economy requires new competencies, and **current jobs in various sectors are likely to shift** with increasing circularity within industries (Sumter et al., 2021). While evidence of the creation of jobs is still an emerging topic in scientific research, recent research in different geographical and sectoral contexts proposes that circularity is likely to lead to task reorientation and a shift in skills. This transition is expected to heavily impact SMEs, with the high costs for investing in training and hiring of

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new qualified workers and missing skills representing an obstacle in the adoption of circular business models (Beducci et al., 2024).

Research on the shift in skills required for CE innovations is relatively new. Recent research results in Flanders (Belgium) show that associated skills shifts can be found in transport and logistics (related to design to lower material use), Research & Development (R&D) and IT skills (related to increases in digitalisation) and technical skills related to the recuperation of waste. The researchers also mention that gender, age, and experience of the entrepreneur will influence the needed skills (Borms et al., 2023). A 2021 study on the skilling implications of the European labour market identifies several categories of prominent skills and qualifications needed in the circular economy transition: (1) increased need for social skills, including collaboration and coordination; (2) higher requirements on work on irregular input (using recycled materials); (3) need for skills to produce reliable and good quality products; (4) skills to work with a complex equipment (especially in the waste management sector); (5) increase in mid-level qualifications (Cihlarova et al., 2021).

Several European initiatives exist to study and facilitate the uptake of such new skills. One example is the SPIRE-SAIS (Skills Alliance for Industrial Symbiosis) project, which develops a comprehensive cross-sectorial blueprint for skills, to enable and accelerate the uptake of IS.

With these shifts there is also the potential to create more inclusive employment opportunities. This could be done by increasing the quality and working conditions of circular jobs, making them more attractive to a broader section of the workforce, specifically people that face disadvantages. Another pathway to more inclusive employment opportunities is through developing partnerships and business models that expressly seek to create jobs for people with a distance to the labour market that would otherwise face barriers to work. This kind of inclusiveness creates job opportunities for the disadvantaged people on the one hand and can mitigate lack of skilled persons companies are facing on the other hand.

3.5.2 Challenges

The main challenges involve societal resistance to change, the difficulty of promoting behavioural shifts during transitions, and concerns related to social justice.

Some authors suggest that there are risks at the societal level when implementing a transition path to a different energy supply, such as a) consumer acceptance (or in this case: social resistance), b) no incentive to change behaviour (e.g., if changes and new infrastructure are not sufficiently communicated or explained), and c) lack of contributions to social justice (also not properly explained or addressed) (Wolkinger et al., 2019).

Societal resistance can for example stem from concerns over environmental justice, fear of pollution, or scepticism regarding corporate motives (Ashton & Bain, 2012). An important point of discussion for example focuses on the financing of circular solutions. From the perspective of the companies involved, investments in circular solutions must be amortised (see Section 3.1). If large investments are necessary, and an increase of market prices for circular products is not competitive, the (possibly controversial) question arises, whether the general public should support investments financially so that acceptable market prices can be realised in the short term. The local level also plays a particularly important role in the context of a societal debate. Reactions, that reject the construction of infrastructure in a specific local area are labelled NIMBY since the beginning of the 1980s (Wexler, 1996). NIMBY reactions have been increasingly studied, especially in the case of energy transitions (e.g., nuclear plants, hydropower, waste facilities, among others), as these transitions require new plants and new infrastructures. They are recognised as an international phenomenon and more recent concerns and motivations for opposition are based on environmental concerns (Popper, 1985 in Wexler, 1996).

The NIMBY term is often used pejoratively and labels such protests as irrational and reactionary (van der Horst, 2007). However, there is a recognisable effort in the academic debate to take a differentiated and multi-layered view of the phenomenon. van der Horst (2007) emphasises that there may well be differentiated motives behind NIMBY protests. Wexler (1996) argues that both a vilifying and a romanticising view of the NIMBY phenomenon is misguiding and characterises the phenomenon as "an

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expression of concern for the growing schism between the public and the private in modern systems" (p. 105).

Following on from this, NIMBY effects and societal resistance should be addressed in order to reverse possible opposition. Appropiate relationships between stakeholders from industry, society, and politics should be the goal, going hand in hand with behavioural changes.

It is important to know that some studies show that there are different moments of NIMBY opposition. One is before the actual implementation of an infrastructure or facility and the other is after (van der Horst, 2007). However, Wolkinger et al. (2019) state that consumer/acceptance topics "mainly (includes) implementation risks". NIMBY moments have been analysed by measuring public opinion, showing that the NIMBY effect can be reversed (van der Horst, 2007), and in some examples the second moment, after implementation, can change an opposition.

Some authors explain these before and after moments as **risks for the transition pathway, when communication is insufficient** and therefore incentives for support are low or inexistent (Wolkinger et al., 2019). In this sense, they suggest that behaviour change should be integrated as an essential part of projections and planning of energy transition projects. A possible cause of emerging conflict can also be seen as a lack of citizen participation, in which possible reservations are not or not sufficiently considered (McKinlay et al., 2024).

Therefore, community collaboration is crucial in IS. Yet, several factors can prevent it. Society can be passive in its engagement (Civiero et al., 2024; Natanian et al., 2024), often due to a lack of awareness, perceived risks, or distrust in industrial actors. Trust is a key determinant in engaging community to collaborate, as communities are more likely to support IS initiatives when they perceive transparency, inclusivity, and long-term benefits (Laybourn & Morrissey, 2009). Effective communication strategies, stakeholder engagement, and co-creation processes are essential to overcoming resistance and building societal trust (Mirata, 2004). Without addressing these social dimensions, IS projects risk facing opposition, delaying implementation, or even failing altogether.

In addition to the interests of citizen and consumers, the interests of employees potentially being affected of shifts in skills and jobs (see Section 3.5.1) also have to be considered to ensure **social justice –** ensuring that they do not lose out and that inequalities are not exacerbated (Brown et al., 2020). To prevent this, the language, and learnings of a 'just transition' are increasingly being adopted in the context of the CE. This concept emphasises the importance of participation, social dialogue, and democratic values. Since the link between CE and social justice is currently considered to be relatively weak, democratic change and social leadership may provide an opportunity to overcome this gap and maximise the CE's social benefits. More concretely, social organisations and trade unions have already established several frameworks and processes to integrate workers at risk of being marginalised by economic transitions in supply chains. Such processes include the formalisation of providing (informal) workers with access to finance, services, and other benefits. Other possible concrete drivers for a more just CE transition can be a proliferation of earmarked funding for the social economy, procurement policies that converge environmental and social criteria, and promoting social justice policies to rectify existing inequalities in value chains (RREUSE, 2023).

Another issue of social justice is the distribution of costs: if people who cannot or do not want to afford circular products are asked to contribute financially (e.g., through taxes) to the circular solutions, this can be considered unfair. Subsidies for sustainable aviation fuels (SAF) – as mentioned for the German hub (see Section 4.1) – could serve as an example for this kind of discussion on social justice.

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4. Hub-specific challenges

4.1 German Hub

The industrial park “Industriepark Höchst” is home to 90 pharmaceutical, chemical, biotechnology and services companies. It is located close to the airport Frankfurt in the German state of Hesse and comprises 120 production plants and 980 buildings. The Processes4Sustainability cluster aims to achieve CO_2 neutrality for the companies located in Industriepark Höchst by further developing and demonstrating CCS, CCU, H_2, bio-based resources and heat pump technologies to establish PtL (power to liquid), PtG (power to gas), PtX, electrolysis of water, H_2 for Fuel Cell trains, and CO_2 as raw material for chemicals, among other innovative ideas (Utikal & Winters, 2024). Companies in Industriepark Höchst are facing the challenges of translating the goal of CO_2-neutrality into their businesses, monitoring technological developments, and taking advantage of public funding. The Process4Sustainability cluster supports companies by providing knowledge, by networking with solution providers, and by pooling resources and investigating public funding opportunities for industry in Hesse (Utikal et al., 2022).

The to-be-demonstrated synergies in focus of this hub for WP3 include CCU and the production of intermediary products which can be further processed to sustainable aviation fuels (SAF; for description of stakeholders look at D3.1 (TUDO et al., 2025), for the technological analysis, see D2.1 (Pfleger-Schopf, 2024)). Stakeholders of the to-be-demonstrated synergies are intensively discussing the enablers and barriers of SAF production (based on the intermediary products of companies in the Höchst Industriepark). As SAF production success is connected to overarching market developments and far-reaching regulatory issues, only some of these stakeholders are located directly at Industriepark Höchst; other relevant stakeholders with interests in SAF-related activities at Industriepark Höchst are located throughout Germany.

4.1.1 Non-technological topics

The expected synergies in the German hub are facing barriers for achieving a market ramp-up for SAF as a final product of CCU at Höchst Industriepark (so that there is currently no business case for SAF). These barriers are referring to non-technological (and technological) aspects. The related key challenges identified by the German hub stakeholders in the interviews, were as follows.

a) Regulations regarding the production and usage of sustainable aviation fuels (SAF)

As the *final product* of the to-be-demonstrated synergies in focus at the German hub is SAF, the regulation regarding SAF is of utmost importance to the success of the analysed companies in the hub (producing pre-products of SAF) and ultimately the IS-synergies itself which means that *regulatory and policy framework* issues are one of the major issues to be addressed in the German hub. It is connected to *environmental effects* and arguments regarding *market and economy*. Producers in the SAF supply chain need proper regulatory framework conditions to estimate demand from aviation fuel suppliers and airlines. Additionally, reliable regulation is needed which allows long-term perspectives for producers, investors and potential customers (cf. DE-P1).

The ReFuelEU Aviation policy of the EU defines which types of e-fuels for aviation are classified as sustainable and count towards the compliance of airlines regarding the quota of SAF usage compared to conventional kerosene. In particular, the question of which types of CO_2 sources can be used to produce SAF represents another regulatory uncertainty (cf. DE-A2, DE-C1, DE-I2, DE-A1). The use of point sources, which is preferred by companies producing intermediary products for SAF, is therefore an obstacle, particularly from a regulatory perspective, as a guaranteed CO_2 saving must be proven and, depending on the origin, use is only permitted until 2036 or 2041 (Richter et al., 2024). While the argument is brought forward by NGOs (cf. DE-C1), that Direct Air Capture (DAC) of CO_2 would be the most sustainable way of reducing CO_2 in the atmosphere, targets for **direct air capture** are still missing in the regulations. As efficiency is still very low, DAC technology has not yet scaled up to the point

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where it can be considered for commercial use, which makes the DAC process very expensive (Richter et al., 2024).

From the point of producers in the SAF supply chain, there is a risk that the period of using CO_2 from point sources (limited to 2036 or 2041 by EU-regulation) is not sufficient to achieve a pay-off for currently built plants (which are currently based on CO_2 from point sources; cf. DE-P1, DE-I2).

The other variable is the quota set for the airlines to use SAF in their mix of fuels. It requires that from 2025 at least 2% of the aviation fuel used comes from sustainable sources. This proportion is to rise to 70% by 2050, whereby more than 35% should come from non-biogenic materials (ReFuelEU Aviation).[9] However, the ReFuelEU Aviation will undergo a review in 2027 which creates uncertainties for investors and companies in the SAF supply chain now (cf. DE-I2, DE-P1, DE-C1). The expected demand for SAF is based on the quotas to be achieved by aviation fuel suppliers. If these quotas will be reduced as a result of the review in 2027, the demand for SAF will be significantly affected. Accordingly, the expected sales on the market of SAF change considerably.

Another issue is the fragmentation of regulation when member states implement the EU policy into national law. A solution for SAF production based on IS may be viable in one country but not in another, even within the EU.

On a regional level, approvals of new plants are an issue for SAF production. Lengthy approval processes can significantly delay the production and the introduction of SAF to the market. It depends on each individual authority how helpful it is in paving the way for new technologies. Public authorities face the challenge of keeping up to date with new technological solutions in order to assess the new solutions and approve them.

To sum up, from the perspective of SAF producers (incl. producers of intermediary products for SAF), investors and customers, these regulatory issues create uncertainties that hinder the market ramp-up of SAF. Some stakeholders mentioned that adopted regulations are not valid long enough for SAF production facilities to amortise. On the other hand, NGOs are interested in solutions which are as environmentally sustainable as possible.

b) The costs of SAF production and SAF competitiveness

When relevant stakeholders discuss the drivers and barriers for the market ramp-up of SAF in publications and at conferences (e.g., Richter et al., 2024, Conference on Sustainable Aviation on 28.11.2024 in Frankfurt, aireg Biennial SAF Conference 2025), it is primarily *market and investment barriers* that are attributed a high level of importance. Specifically, it is the cost of producing SAF, its impact on profit margins and competitiveness (e.g., of airlines and the mineral oil industry) as well as investment risks that are highly relevant to ramping up SAF.

Market barriers

The high cost of SAF compared to conventional jet A-1 fuel is a significant barrier. High production costs lead to low expected return on investments in plants for the production of SAF. The investments are associated with high costs for the synthesis plant, possibly for CO2 extraction by means of direct air capture (DAC) or separation (Richter et al., 2024). The construction of such facilities and the

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[9] When it comes to the national implementation of the ReFuelEU avation, the countries are able to set stricter requirements which leads to differences between the member states. As the German requirements have generally been stricter in recent years, SAF produced in Germany can still be used in other European countries. While additional national regulation is also possible, however, adjustments are becoming apparent here.

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associated costs require long term off-take agreements between the parties involved – but this does not fit in with the flexibility (requirements) of airlines. Furthermore, the cost of SAF production is significantly influenced (could be up to 50 % of SAF costs) by the cost of renewable energy, respectively hydrogen, and other resources such as water and CO_2. Due to the high costs of SAF, there is very limited demand for SAF – despite EU regulation making it obligatory for airlines[10] (DE-A1, Richter et al., 2024).

As fuel costs represent around 30% of airlines' costs (International Air Transport Association, 2024b), the higher costs of SAF have a high impact on their margins (and possibly competitiveness). At today's costs (3-10 times higher cost of SAF (Smeets, 2024) and airline margins of approximately 5% (International Air Transport Association, 2024a)– and assuming that airlines cannot pass on the higher costs to customers – adding 4-5% SAF to jet fuel would result in negative margins for airlines (cf. DE-P1). This makes it very likely that airlines will pass on the higher costs to their customers (passengers and freight customers). The willingness of private customers to accept higher ticket prices is very limited (cf. DE-A1). Business customers (passengers, cargo customers) are more willing to accept a higher cost, as the use of SAF leads to an improvement in the carbon footprint and thus has a value for business customers (cf. DE-A1; given the case that CO_2 savings are certified and acknowledged). In this context, **airlines** emphasise their competitiveness compared to airlines whose aircrafts are refuelled at hubs outside the EU, which is based on lower fuel costs (cf. DE-P1). On the other hand, an interviewed NGO representative has countered this argument, saying that the effect should not be that large with the current quota and prices (cf. DE-C1).

Investment barriers

Companies such as CAPHENIA and INERATEC are developing and deploying technologies to produce intermediary products for SAF (synthesis gas, wax). They need investments and funding to develop medium- and large-scale production plants and show that SAF production is efficient and effective enough to be profitable. However, the complexity of SAF production is so high that investors have shown little interest so far. The risks are too complex for banks to provide financial resources for the ramp-up (Ziegler, 2024). The willingness of investors and financiers to invest depends on a (long-term) reliable *regulatory framework* and clear market prospects for new technologies (cf. DE-A2, DE-P1, DE-I2). The regulatory risks have already been mentioned above: in view of the upcoming review of ReFuelEU Aviation in 2027 and the possibility that the current requirements for the use of SAF quotas could be watered down, the amortisation period of a corresponding investment is uncertain. Beside the regulatory risks, investors, such as banks and venture capital firms are hesitant because of high investment volumes, low demand for SAF, high complexity of SAF production, technological risks[11] and first-mover disadvantage (Ziegler, 2024). Thus, *organisational capacities and profitability* are a very relevant category of non-technological issues in this hub. To summarise, there is no business case for SAF as long as these investment risks are high, and potential returns are low (Richter et al., 2024).

In addition to banks, venture capital companies and other financial institutions, this also applies to companies in the mineral oil industry: the transition to SAF would require billions of dollars of investments, which representatives of the oil industry consider unattractive without a solid and predictable legal framework (cf. DE-A1). Furthermore, mineral oil companies cite the low demand from airlines and their unwillingness to pay the higher prices of SAF, as well as the high production costs of SAF, as the main reasons for not investing themselves. For oil companies, the focus often lies on global

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[10] According to Richter et al. (2024), this is because the costs of fossil fuel, CO2 certificates and penalties for non-compliance with the ReFuelEU Aviation are lower than the SAF costs. This only applies to the German e-fuel penalty. The EU penalty is based on twice the difference between conventional aviation fuel (CAF) and bio-SAF and e-SAF.

[11] The technological risk for SAF production is that SAF production processes are not yet available on an industrial production scale and do not yet have the technical maturity relevant for investors (Richter et al., 2024).

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profitability rather than the regional reduction of greenhouse gas emissions. (cf. DE-A1). In addition, mineral oil companies are also cautious because jet fuel is only a niche product compared to diesel and petrol (Richter et al., 2024).

Insufficient political (financial) support

The outlined barriers show that there is currently no business case for the production and use of SAF (and its intermediary products). Therefore, industry stakeholders argue that the state is required to provide risk protection, start-up financing and planning reliability. At least for Germany, however, there is room for improvement: air traffic tax has increased, but the revenue was transferred to the general budget and not invested in SAF. To foster SAF ramp-up, at least 50% of the tax revenue would have to be channelled into SAF funding. Instead, all approved funding for SAF ramp-up was cancelled following the ruling of the Federal Constitutional Court on the financing of the Climate and Transformation Fund (Barth, 2024). It is interesting to note, that – outside of Germany – airlines are committed to SAF, even investing in plants (Ziegler, 2024).

c) Societal impacts of SAFs

The expected rising costs of air travel for citizens as consumers leads to *societal effects* that can lead to a broader discussion on who should pay for the price of the transition from fossil-based kerosene to SAF and to what extent, who should have access to air travel, or to what extent public money should be spent to support the SAF sector. This is where social impact becomes relevant for the German hub, as issues of *resistance and trust* are key. These discussions touch on the aforementioned issues of SAF production and the associated *regulatory, environmental and economic issues*.

The impact of an increase in SAF usage on the cost of flights for travellers can lead to a further exclusion of less affluent groups of the population as well as to economic loss of airlines. At the moment, only a small percentage of ticket buyers chose to pay the voluntary fee for CO_2 compensation. This could indicate that more expensive ticket prices lead to a reduction in air travel and potentially a loss of profit margins for airlines, which is already a relatively low margin (cf. Dietrich, 2024).

Another hypothesis for why only 5% of passengers are willing to pay a voluntary surcharge for SAF is that passengers have limited confidence in airlines to actually spend the additional revenue on SAF. Discussions are currently underway to identify additional stakeholders in which passengers might have greater confidence (see e.g., Conference on Sustainable Aviation; Zimmer, 2024). These issues that affect the market for air travel and society need to be further discussed in the German hub.

Social acceptance is also an important factor for the success of H4C in general and for SAF in particular. NIMBY (as mentioned in Section 3.5) is a widespread phenomenon that occurs not only with regard to industrial infrastructure measures (e.g., construction of an incineration or recycling plant), but also with regard to the construction of wind turbines, power lines, and other new infrastructure for energy production. In the context of the SAF ramp-up, citizens' concerns regarding pipelines for CO_2 and hydrogen in the vicinity of the industrial park need to be addressed proactively and early in the process of IS implementation. The former structures of citizen consultation regarding noise of aviation around Frankfurt airport could be revived for the dialogue about the pipelines or other issues of concern. This is a successful public engagement model based on a mediation process in response to aircraft noise conflicts. Those who were directly affected from the region in decisions regarding flight operations were involved in this mediation process. Many stakeholders came together in various processes within this framework.

d) Disagreement about infrastructure and energy provision for SAF production between industry and policy

For the German hub's upscaling of SAF production (incl. its intermediary products), the provision of infrastructure by the state and energy suppliers is of great importance. Although the generation of

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renewable energy has increased sharply in recent years (mainly due to electricity generation in offshore wind farms in northern Germany), the transport of renewable energy has been slow. However, the transport of renewable electricity has been hampered because the necessary power lines are not available to a sufficient extent. The reasons for this lie in political decisions by the German government, a lack of social acceptance, but also in bureaucratic hurdles, as the grid provider needs a separate licence from each municipality through which a power line passes. The construction of a hydrogen infrastructure has also been postponed by the last German government from 2028 to 2035 (cf. DE-I1). This makes the German energy infrastructure a significant barrier to the energy transition - away from fossil fuels and towards the electrification of processes, the shift from natural gas to hydrogen and the production of e-fuels (including sustainable aviation fuels), which are absolutely dependent on the availability of renewable energies and hydrogen.

This makes the construction of suitable infrastructure a key factor in securing the location of energy-intensive companies in Germany in general and the companies in Industriepark Höchst in particular. The high energy prices in Germany are also a major factor in jeopardising the competitiveness of SAF produced in Germany. This situation is also prompting the related German trade union, which is committed to securing the location of chemical companies in Germany and thus also to securing jobs for the employees in these companies (cf. DE-I3). On the one hand, this happens through dialogue with politicians, and on the other hand, the trade union also engages in dialogue processes with citizens who are sceptical about the construction of new infrastructure. To a large extent, these are also employees in companies at Industriepark Höchst, with whom the trade union then enters into dialogue – for example, by creating transparency about the respective infrastructure measures and their objectives and giving employees the opportunity to put forward their *social and environmental* points (cf. DE-I3). Regarding this key challenge, non-technological issues regarding the *societal dimension, regional development and interorganisational collaboration, political framework* aspects and *economy and market* need to be further addressed.

e) Job creation and related topics in the German hub

Industriepark Höchst is one of the largest sites for the chemical and pharmaceutical industry in Europe. As mentioned previously, it contains around 90 different chemical and pharmaceutical companies on site of the hub. The site hosts businesses of different sizes, ranging from 2 to 7,000 employees, and in total hosts roughly 20,000 employees in an area of 6.4 km^2.

This high concentration of employment is due to R&D activities and services (maintenance, logistics, distribution). The hub is also facing challenges, with large companies producing chemicals having closed in recent years.

A key topic that influences the hub's employment potential is related to the increase in energy prices in Europe, particularly since the COVID-19 pandemic. The high costs of energy are particularly problematic for chemical companies competing on the international market. Therefore, the expectation is that, independently from the IS2H4C project, the number of employees onsite will decrease.

Another challenge is that a lack of clarity regarding green hydrogen/alternative energy sources is slowing down investment, which makes the future of the usage of these sources currently uncertain.

On a more positive note, at the time, industrial parks play a role as innovation campuses. They help to bring technology projects from lab to first industrial scale (e.g., 10-20 or 100 jobs in some cases). Several examples of such potential scale-ups are found in the Industriepark Höchst.

The operator of the hub is a key stakeholder and employer, as it services the hub by delivering logistics, in education, energy, waste treatment, authority management – whatever is needed to focus on core processes. With respect to changes in skills as a result of the to-be-demonstrated synergies, it is not expected that the skill demand will change for the operator of the hub. The company exists on the basis that it can service companies that are part of the hub. An example of this is that it delivers heat to occupants of the park – electricity as a by-product of heat, which is served to the park.

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4.1.2 Addressing key challenges

The challenges for the ramp-up of SAF production (and its intermediary products) are well known. Projects such as Innofuels[12] enable stakeholder collaboration, organisations such as CENA are systematically addressing these challenges, for example through conferences such as “Sustainable Aviation” in 2024, the Aviation Initiative for Renewable Energy in Germany (aireg) is hosting a SAF conference in 2025 – to name but a few examples of the wide range of activities fostering SAF in the EU. The working group on sustainable aviation (AKKL, established by the German Government) provides a forum where many stakeholders discuss SAF-related topics (cf. DE-C2). Thereby, the general SAF challenges on EU and national level seem to be addressed, albeit not sufficiently as many more stakeholder workshops are needed to work consequently on the SAF related issues (Ziegler, 2024).

In the IS2H4C project, it is foreseen that non-technological challenges (identified by interviews and surveys among stakeholders) will be addressed within Living Labs. Therefore, and while challenges on national/European level are already addressed by the organisations, networks and conferences above, the living labs of IS2H4C will focus on stakeholders and challenges at a regional level. In order to use the momentum of already existing working structures on SAF, the IS2H4C project plans to collaborate with the Innofuels project (incl. the multi-stakeholder approach of CENA) and with the Processes4Sustainability cluster. Both already established a collaboration with stakeholders in and around the Höchst Industriepark.

4.2 Dutch Hub

The Dutch Hub in Almelo, Netherlands, is anchored by two main entities: H_2Hub Twente and Almelo Energie. H_2Hub Twente unites businesses, government, researchers, and knowledge institutions to advance hydrogen technology through pilot projects in areas such as energy generation, storage, mobility, industrial processes, and the built environment. Almelo Energie, Twente’s first Positive Energy District (PED), drives energy transitions with initiatives like natural gas-free neighbourhoods, energy balancing, demand response, and district-level self-consumption. The hub integrates hydrogen production with solar energy, wastewater treatment, office buildings, and a crematory. The IS2H4C initiative highlights synergies, such as using oxygen from hydrogen production for wastewater treatment, repurposing treated water for hydrogen generation, and replacing natural gas with hydrogen in crematories and residential heating. Further opportunities include biogas-based combined heat and power (CHP) from cattle manure, waste heat recovery from electrolysis for office heating, and hydrogen distribution via fuel stations and trucks to reduce fossil fuel use. These efforts focus on enhancing technology readiness levels (TRLs) for waste heat recovery, oxygen use in wastewater treatment, and water reuse in electrolysis.

The stakeholders in the Dutch hub are organised in three main tiers (from Tier 1 to Tier 3, dependent on their contribution and involvement) and, similar to the other hubs, divided by stakeholder category (society, academia, industry, and policy). We refer to Deliverable 3.1 (see TUDO et al., 2025) for an overview and description of the most important stakeholders in the Dutch hub.

The stakeholders within the Dutch hub are strongly interconnected through their collective commitment to energy transition and industrial symbiosis. Almelo Energie works closely with communities and municipalities to secure social acceptance for energy transformations, drawing on academic and institutional support while leveraging technological expertise from NL-I4 and infrastructure knowledge from NL-I3. NL-A1 facilitates collaboration between industries, academia, and local communities by fostering knowledge exchange and promoting pilot projects that showcase IS in action, driving both technological advancements and social integration. NL-I4 contributes essential hydrogen production and storage solutions, while NL-I3 ensures the seamless integration of hydrogen, electricity, and gas within the regional energy network. Advancing the energy transition and achieving sustainability goals

[12] https://www.innofuels.de/

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require these stakeholders to coordinate efforts, exchange expertise, and secure funding while overcoming challenges related to infrastructure alignment, policy uncertainties, and regulatory barriers.

4.2.1 Non-technological topics

The analysis of the Dutch hub has focused on the IS of hydrogen energy technology application in industries and surrounding communities. Stakeholder mapping reveals connections among all stakeholder categories (government, academia, society, policy), see Deliverable 3.1 (TUDO et al., 2025). Based on the interviews conducted in the Dutch hub (for details we refer to Deliverable 3.1), collaboration among the stakeholders faces significant non-technological barriers that stem from (a) regulatory uncertainties, (b) economic challenges and resource limitations, (c) coordination difficulties with misaligned stakeholder priorities, (d) societal impacts / community relations, and (e) job creation and related topics.

a) Regulatory uncertainties

Lack of clear legal frameworks for energy-sharing and IS hinders planning and scaling. Hydrogen storage, transportation, and distribution regulations remain unclear, delaying investments. Slow and bureaucratic approval processes discourage stakeholders.

One of the main obstacles and most pressing barrier for the interviewed stakeholders in the Dutch hub is the absence of well-defined and supportive regulations for IS and energy-sharing initiatives. NL-S1 and NL-I4, for example, operate in a landscape of legal uncertainty regarding energy-sharing systems and hydrogen production, as Dutch policies on energy communities are still under development. NL-I3 faces ambiguity surrounding its role and responsibilities in hydrogen distribution, making it difficult to plan and expand infrastructure effectively. NL-I4 also encounters regulatory hurdles due to unclear government policies on hydrogen storage and transportation. Similarly, NL-AI must navigate vague regulations concerning energy-sharing mechanisms, such as repurposing waste heat or utilising hydrogen. Without a clear legal framework at both the regional and national levels, stakeholders experience operational uncertainty, challenges in long-term planning, and delays in scaling up pilot projects into fully developed solutions.

Regulatory and governmental decision-making processes tend to be slow and bureaucratic, significantly impacting the pace of innovation. NL-S1 and NL-I3, in particular, emphasise that the prolonged approval processes at regional and national levels present a major challenge, as they must work through complex legislative procedures while attempting to implement advanced energy solutions. For NL-A1, the transition from pilot projects to larger-scale initiatives requires multiple layers of approval from funding bodies, local authorities, and regulatory agencies. These drawn-out processes can make stakeholders hesitant to engage in collaborative efforts, as uncertainty and delays create barriers to progress.

b) Economic challenges, resource limitations, and capabilities

High costs of hydrogen production, storage, and conversion (compared to fossil fuels) limit adoption. Smaller stakeholders like NL-S1 struggle with funding and human resources for outreach and community engagement (limited financial incentives and subsidies for IS projects). Addressing gaps requires collaborative resource pooling, but uncertainty in long-term return on investment discourage private sector involvement.

As a small, volunteer-driven organisation, NL-S1 faces significant limitations in financial and human resources, making it challenging to conduct extensive stakeholder outreach and engagement to legitimise their initiatives and compete for funding opportunities. Similarly, NL-I3 recognizes that their expertise in key areas such as hydrogen distribution is still developing, with only a limited portion of their workforce trained in this specialized field. While NL-I4 possesses strong technological capabilities, the high costs associated with hydrogen production, storage, and conversion remain a barrier to widespread adoption. These resource limitations slow progress and put pressure on collaboration,

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highlighting the need for shared investments and collective resource allocation to bridge these gaps effectively.

c) Organisational & collaborative capacities

Misaligned stakeholder priorities create tensions between community-focused, technological, and regulatory interests and slow down decision-making. Effective coordination requires frequent communication, clear role division, and strong leadership. Institutional differences add complexity to partnerships. There is a lack of specialised workforce and training programs for new energy technologies.

NL-S1 places a strong emphasis on community empowerment and social infrastructure, striving to ensure that residents directly benefit from energy initiatives. In contrast, NL-A1 concentrates on technological advancements, efficiency improvements, and scaling up sustainable energy solutions. NL-I4, as a hydrogen technology provider, focuses on accelerating the energy transition through hydrogen production and storage, positioning itself as a leader in clean energy innovation. As a grid operator, NL-I3 works toward modernizing infrastructure to accommodate the integration of hydrogen alongside gas and electricity, aligning with its municipal and safety responsibilities. These differing priorities can create friction, as industry players prioritize *profitability and scalability*, whereas communities are more concerned with long-term *environmental* and *social impact*. Overcoming these differences requires clear communication, mutual understanding, and a commitment to finding shared objectives.

Institutional practices and organizational cultures further shape collaboration dynamics, sometimes leading to misalignment. Academic institutions such as NL-A1 emphasize research and innovation, whereas municipal governments focus on policy implementation and regulatory compliance. At the same time, volunteer-driven organizations like NL-S1 tend to operate with flexible, informal structures, which may not always align with the more standardized procedures followed by industrial and governmental partners like NL-I3. NL-I4, with its technology-oriented approach, must find common ground with the public-focused missions of NL-S1 and NL-I3. Ensuring effective collaboration requires harmonising these different operational styles.

Bringing together multiple stakeholders with distinct objectives, structures, and timelines presents an ongoing coordination challenge. NL-S1 faces difficulties navigating varying municipal regulations, which hinder the creation of a uniform approach to energy initiatives. NL-I3 must align its technical capabilities with *regulatory requirements* while coordinating efforts with municipalities, emergency services, and industry partners. Limited stakeholder outreach restricts the stakeholders in the Dutch hub to secure community support, which is crucial for legitimising their initiatives, and makes it harder to compete for larger funding opportunities. NL-I4 needs to integrate its hydrogen technologies into broader energy networks while adjusting to infrastructure and policy developments alongside NL-S1 and the *H_2Hub*. For NL-A1, facilitating collaboration among industries, communities, and government bodies involves balancing competing priorities and addressing misconceptions about the benefits of IS. Successful coordination requires strategic planning, regular communication, well-defined roles, and strong leadership.

d) Societal impacts (Community relations)

Public scepticism and concerns around emerging technologies like hydrogen safety and IS requires trust-building. NL-S1 faces challenges in gaining local acceptance, while NL-I4, for instance, must ensure transparent risk communication. Public education and awareness campaigns are key to avoid social resistance to large-scale energy transformations in local communities.

Gaining community support is crucial but often difficult, particularly when IS initiatives involve technical complexities (see point b)) or concerns about potential disruptions, such as noise, pollution, or safety risks. For NL-S1, reaching and educating local communities requires substantial effort, but limited resources and a lack of awareness among residents make this process more challenging. To address

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these issues, awareness-building efforts – including public events, educational programs, and clear, transparent communication – are essential to fostering trust, improving stakeholder alignment, and ensuring long-term community engagement.

Building awareness and trust remains a significant challenge, particularly for NL-S1, and NL-I3. NL-S1 often encounters scepticism from local municipalities and stakeholders who view their projects as too informal or experimental. Both NL-I3 and NL-I4 face the task of ensuring the safety of hydrogen technologies and fostering public trust in their reliability, collaborating with entities like the Twente Safety Campus to train emergency response teams. Inadequate communication or a lack of transparency can exacerbate these trust issues, creating additional obstacles to effective collaboration. Overcoming these challenges requires clear, transparent communication and targeted public education efforts.

e) Job creation and related topics in the Dutch hub

Representatives from the Dutch hub were interviewed for first insights into the topics of job creation and skills changes as a result of the to-be-demonstrated synergies in the hub. While the results from the inventory sheets of the identified stakeholders are still in development, the interviews provided first insights.

With respect to NL-S1-B and the shift from natural gas to H_2 in five residential buildings in Aadorp, network operators were identified as relevant stakeholders regarding changes in employment and skills. For another pilot of a similar nature, staff was re-trained in order to obtain the necessary installation and maintenance skills for hydrogen infrastructure. This is expected to be similar in the case of the Dutch hub, and this re-skilling was identified as the most significant change related to the activities of Almelo Energie. For NL-I2, several other skills-related changes were identified. Two key stakeholders will experience a change in personnel skills: 'Waterschap' (the waterboard), and the water treatment services company. The changes in skills will consist of new combinations of electrical engineering, water engineering, process/installation engineering, and permits/safety knowledge. The exact combination is still unknown, but the NL-I2 has set up 'learning communities' to study the needed changes in skills.

Thirdly, the hub is experimenting with the storage of energy by installing solar capacity, small wind turbines and battery capacity. The role of H_2 in such an energy system will be investigated as part of H_2Hub Twente. If successful, the implications for jobs and skills may also be investigated by a to-be-launched Learning Community.

4.2.2 Addressing key challenges

To overcome the key challenges in the Dutch hub, several actions are necessary:

Strengthening legal frameworks: In order to overcome the *regulatory uncertainties*, a stronger, clearer legal framework is needed to support IS. This would provide clear guidelines, enabling stakeholders to plan, invest, and scale their projects with confidence.

Addressing community concerns: Community concerns about potential disruptions – such as noise, pollution, and safety risks – must be addressed proactively. It is crucial to ensure that hydrogen production and other energy transition efforts align with sustainability goals, taking into account their potential unintended environmental consequences. Transparent communication, along with long-term impact assessments, will be essential to build public and regulatory support for new technologies. Our IS2H4C project's living labs will provide a platform for discussing regional challenges and fostering better alignment between stakeholders, considering the mentioned *societal dimensions, environmental effects* and *regulatory aspects*.

Optimising infrastructure: Grid modernisation is a critical requirement for integrating hydrogen, electricity, and gas. The current mismatch between grid capacity and future energy needs poses a significant challenge. In order to overcome *economic challenges* and *resource limitations,* technical capabilities need to be aligned with evolving regulations. This remains a challenge for instance for NL-

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I3. Scaling up IS initiatives relies on infrastructure investments, effective coordination, and overcoming the complexities of upgrading existing infrastructure, which many interviewees identified as a high-cost and high-complexity issue.

Building awareness and trust: Building public trust in emerging technologies such as hydrogen is crucial to overcome *societal issues* in *community relations*. Drawing upon the extensive experience of industries like the chemical sector in hydrogen handling can be helpful to ensure safety and mitigate public concerns. Ongoing, transparent public communication, along with community engagement through educational programs, will also be key in fostering acceptance amongst the society.

Managing stakeholder complexity: Managing the diverse stakeholder landscape will require continuous effort. Stakeholders have different priorities, timelines, and expectations, and navigating these differences demands regular workshops, long-term engagement, and careful negotiation of interests.

Leveraging living labs: Given the challenges in aligning stakeholder priorities and addressing infrastructure complexities, living labs offer an invaluable opportunity. These labs will enable stakeholders to negotiate their interests, test technologies, and collaboratively develop solutions. Living labs will be an essential part of the methodology – serving as the final step in the process of Identification-Assessment-Addressing (see Chapter 1).

4.3 Basque Hub

The Basque Country is one of the largest industrial concentrations in Europe, with a significant presence of energy-intensive and emission-intensive sectors. In this context, the Basque Government-SPRI leads the strategic initiative Net-Zero Basque Industrial SuperCluster (NZBISC), in collaboration with the two main energy companies in the region, Iberdrola and Repsol-Petronor, with the double objective of accelerating the reduction of emissions in the Basque industry, while also promoting new opportunities for companies in the Basque area for the development of new technologies to innovative decarbonisation services.

NZBISC, which is part of the World Economic Forum's (WEF) Transitioning Industrial Clusters Towards Net Zero program, has put the initial focus on the five industrial sectors with the highest amount of energy consumption and GHG emissions (Oil refining, Steel, Foundry, Cement, Pulp and Paper) and worked together with the industrial cluster associations that represent those sectors in the development of sector-specific decarbonisation roadmaps. With the aim of promoting inter-company collaboration in the development and deployment of these technologies and solutions, the Basque Energy Cluster has established the DCARTECH Alliance with the associations representing the sector prioritised by NZBISC: ACLIMA (cement), AFV (foundry), SIDEREX (steel), and CLUSTERPAPEL (pulp and paper). The alliance has launched the new *Industry Decarbonisation Forum*, as the main meeting point between technological solutions providers and industrial end-users, i.e., between the supply and demand sides.

The Forum, led by the Basque Energy Cluster, acts as a dynamisation tool of the NZBISC initiative, aiming to facilitate networking among the value chains and the identification of opportunities for collaboration in the decarbonisation field. Presential, face-to-face events, are held quarterly, with the participation of more than 150 representatives of Basque companies and technology centres.

In this framework of collaboration, last year, a group of Basque companies decided to explore some of the cross-sectoral synergies that had been identified in the decarbonisation roadmaps of NZBISC and joined the European project IS2H4C together. The so-called Basque Industrial Hub for Circularity (BIH4C) involved in this project is comprised of ten companies from the oil refining, steel, paper, and lime sectors, i.e., the same sectors in which NZBISC has been focused on so far plus the lime sector. Within the IS2H4C project, there are three implementations of IS in focus: 1) Oxy-Combustion and use of green hydrogen from oxygen and hydrogen produced by an oil refinery as by-product, using NORTEGAS infrastructure for transport 2) Carbonation of steel slags using captured CO_2 from the lime

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industry and 3) Production of synthetic fuels using captured CO_2 from the lime industry and hydrogen produced using renewable energy.[13]

4.3.1 Non-technological topics

Several non-technological issues need to be addressed in the hub to overcome barriers and implement these IS successfully.

a) High need of capital and operational expenditures

Hub representatives interviewed pointed out that ***economic and market*** **factors** are one of the main challenges for the implementation of industrial symbiosis. In particular, the economic barrier is key to adopting technologies such as the use of green hydrogen or CO_2 capture.

Adapting existing industrial infrastructure to incorporate these technologies requires **high investment costs (CAPEX)**. Moreover, the lack of technological maturity increases uncertainty, as certain key parameters, such as the impact of these processes on the quality of the final product, have not yet been studied in depth. Before the industry can take on these investments, it is essential to advance in research to improve technological maturity, reduce uncertainty and generate confidence in the sector.

To this end, collaboration between technology centres, universities and industry is essential. This cooperation will make it possible to identify the main technological challenges, develop joint projects that optimise resources and direct lines of research towards viable solutions. Only then will these technologies be able to reach a sufficient degree of maturity to be implemented on an industrial scale.

Beyond technological feasibility, another critical factor is **the need for a solid transport and storage infrastructure** for both hydrogen and CO_2. The specific requirements of the Basque industry are currently being assessed with the aim of planning strategic investments to guarantee a stable supply of green hydrogen to the industry. In parallel, some companies have begun to carry out tests at their facilities to analyse the feasibility of implementing these technologies and assess the necessary modifications to their production processes.

However, the lack of adequate infrastructure is hindering the progress of the implementation of these technologies. Without a continuous supply of hydrogen, it is impossible to conduct representative industrial tests to obtain real data on the barriers to fuel switching. As a result, both the technological development of these solutions and investments in equipment and infrastructure are slowing down.

In addition to the high investment costs and lack of technological maturity, these technologies have **high operational costs (OPEX)** due to their intensive use of electricity. Green hydrogen production requires electricity from renewable sources, which makes it less competitive with fossil fuels such as natural gas. Similarly, carbon capture involves significant energy consumption which increases operating costs.

In this sense, the decarbonisation of industry is driving greater electrification of production processes, which in turn puts pressure on electricity distribution grids, which are not prepared to absorb this increased demand. The lack of capacity in the distribution network is creating constraints for industry, underlining the **need for urgent investment in electricity infrastructure**.

To enable this transition, it is essential to reinforce the distribution grid, increasing its medium and high voltage capacity, modernising its management and implementing advances in digitalisation and cybersecurity. However, these investments face significant regulatory barriers, such as the complexity and slowness of the planning and authorisation processes, the lack of adequate incentives for grid

[13] This description of the Basque hub is in its largest part taken from the internal deliverable D3.1 of the IS2H4C project (TUDO et al., 2025).

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operators and restrictions in financing models. This makes it difficult to implement them in the timeframe necessary to accompany the electrification of the industry.

On the other hand, industry stakeholders point out that there is still a need to **develop business models** that ensure the economic sustainability of the industrial symbiosis and allow the industry to remain competitive, despite the current high investment and operating costs. Finding solutions to this challenge will also require strengthening *organisational and collaborative capacities*, considering aspects such as the profitability of the participating companies, the development of adequate organisational structures and effective cooperation between the different actors involved.

b) Regulatory and bureaucratic inefficiencies exacerbate challenges for the Basque hub, with slow permitting processes and unclear legal frameworks.

Different issues from the category of the ***regulatory and policy framework*** form the second key challenge in the Basque hub. Interview partners report that permitting and licensing processes by regional authorities are slow compared to economic requirements of IS implementation financing in many cases. In other cases, it is rather uncertainty that arises from legislation that hinders the implementation of IS projects. The uncertainty can stem from the complexity of regulations or the uncertain prospect of when and how regulations will change in the near or medium-term future. Finding a path towards feasible transition to IS for companies would require planning security in terms of environmental and industrial policy compliance as well as finding ways of facilitation between companies and regional authorities in permitting and licensing processes. The *collaborative capacity of spatial dynamics and collaboration* come into play in this issue.

As explained in the previous section, **regulatory barriers around grid upgrading** are slowing down the adoption of decarbonisation measures in industry. The current regulatory framework establishes both a financial remuneration rate and restrictions on the financing models allowed for distribution system operators. According to them, these conditions do not adequately reflect the real costs of the investments needed to upgrade the infrastructure, which is holding back investments. Both industry and grid operators are calling for a regulatory approach to ensure that the expansion and modernisation of electricity infrastructure is in line with the industrial sector's decarbonisation plans.

Another regulatory aspect that can influence the adoption of emission reduction strategies or the implementation of industrial symbiosis schemes is the **Emissions Trading Scheme (ETS)**. Currently, this system combines a partial allocation of free allowances with another part that must be purchased to offset CO_2 emissions. However, this free allocation is expected to be phased out in the future. This development of the regulatory framework has a direct impact on the economic viability of emission reduction strategies, as a measure that may not be cost-effective today could be cost-effective in the future if it leads to savings in the costs of purchasing emission allowances.

In addition to these regulatory measures**, restrictions on the use of landfills** have posed an additional challenge for industry. While these limitations aim to reduce environmental impacts, many companies face difficulties in adopting alternatives such as recycling or waste recovery. High upfront costs and complex administrative procedures slow down the implementation of these solutions.

For these regulations to make a real contribution to industrial transformation without compromising competitiveness, it is essential to complement them with policies that encourage innovation, financing instruments for clean technologies and a stable regulatory framework. Only in this way will companies be able to plan their transition with predictability and remain competitive with industries in other regions with less stringent emissions regulations.

c) Social resistance is another recurring barrier, with opposition to new renewable energy installations, waste management facilities, and CO_2 storage sites reflecting broader public concerns.

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The interviewed stakeholders have repeatedly mentioned that there is resistance against infrastructure projects or the implementation of certain new technologies in the Basque country. This resistance has delayed or hindered the implementation if IS projects.

Examples given were the planned installation of wind farms and solar energy installations, as well as waste management and valorisation infrastructures. It might be the case, that issues about missing transparency and trust between industry and citizens lead to a “NIMBY”-attitude of citizens, where a general agreement exists that a transition to renewable energies and circular economy should be the goal, but the construction of necessary infrastructure should take place “NIMBY”. Thus, the discussion of this challenge involves *societal* and community relations issues, such as *resistance and trust* and *societal level effects* of IS implementation.

Accordingly, the Social Network Analysis described in D3.1 fosters this finding: “Society consistently has minimal cooperation with all other stakeholders. Society scores low in information-sharing frequency, suggesting a lack of active engagement or integration into the hub’s activities.” (TUDO et al., 2025)

The engagement of citizens and communities, such as awareness raising, opening dialogue, and being transparent about planned projects and their goals and impacts in the vicinity should be addressed by the hub. It should be aimed at establishing formats of dialogue that engage citizens, regional policy makers and industry.

d) Job creation and related topics in the Basque hub

The BIH4C includes steel, cement, lime, oil refining and pulp & paper industries. Additionally, the hub applies already existing technologies for wastewater treatment, waste pyrolysis, electrolysis, e-fuel production in transportation.

The key identified to-be-demonstrated synergies in the Basque Hub are:

- Using either O_2 resulting from electrolysis for oxy-combustion or hydrogen in steel production to reduce fossil fuel consumption.
- Captured CO_2 will be utilized in lime production.
- Steel slag and CO_2 will be used in carbonation to produce construction products for the cement industry.

The main aim of these synergies is to demonstrate the use of hydrogen and oxygen. This is therefore also the domain where the most significant changes in employment will take place. The following key stakeholders were identified to play a key role in these to-be-demonstrated synergies: Sidenor, SBS, Calcenor, Lointek, Tecnalia. They have been contacted with a jobs inventory sheet to assess their current employment associated with the hubs, as well as the expected changes as a result of the to-be-demonstrated synergies, both in terms of job creation as well as in terms of changes in skills.

With work still being in progress, first results provide relevant insights into the changes in skills at the Basque hub. Up to 2027, it is expected that a significant change in skills as a result of the to-be-demonstrated synergies will be centred around handling new equipment, as well as new tasks during the production process and the maintenance of the equipment. Workers are currently trained to handle the new equipment. New skills in security, as a result of new technologies applied, will be key as well. It was also emphasized that maintenance work will change significantly, which may be done by subcontracted parties.

An important note is that each of the companies that are involved in the pilot demo tests are also involved in many other projects. The engineering, R&D or production departments will dedicate some of their staff, sometimes for a few months, to these to-be-demonstrated synergies. Therefore, the hub does not expect immediate job increases as a result of the activities.

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4.3.2 Addressing key challenges

The high need for capital for IS implementations and necessary infrastructure are well understood by hub members. Collaboration between companies from the different sectors and public authorities is already happening by the **Basque Hydrogen Corridor (BH2C)**, with over 70 member organisations. Similarly, the **NZBISC** is an initiative addressing decarbonisation of energy-intensive industries and is led by the public agency SPRI. NZBISC is part of the World Economic Forum's *Transitioning Industrial Clusters Towards Net Zero* program and has put "the initial focus on the five industrial sectors with the highest amount of energy consumption and GHG emissions (**Oil refining, Steel, Foundry, Cement, Pulp and Paper**) and worked together with the industrial cluster associations that represent those sectors in the development of sector-specific decarbonization roadmaps." (TUDO et al., 2025). The clusters representing the sectors involved in the NZBISC have also formed the **DCARTECH alliance**, coordinated by the Basque Energy Clusters and have launched the Industry Decarbonization forum. Accordingly, different sectors and public already have working structures established that can be built upon in the living labs that are planned for addressing the key challenges in the further course of the IS2H4C project. This should include working on business case identification and dialogue about how to finance necessary infrastructure and high investments.

Similarly, the mentioned initiative NZBISC gives the opportunity to open the dialogue between the public administration and industry about permitting procedures and necessary legislative clarification for the further development of IS implementations as described in key challenge 2. For the specific issue of hydrogen infrastructure there is also the BH2C that brings together industry and public authorities and where *regulatory* hurdles can be discussed.

For the key challenge of social resistance and the connected question about citizen engagement, hub representatives have not reported any established working structures they knew that consults or informs citizens or civil society representatives about the IS endeavours. This topic should be taken up in the living labs and a strategy to establish connections to civil society and specifically citizens in the vicinity of IS implementation project need to be developed, which will hopefully lead to the engagement of citizens in the near future. Public stakeholders would be the first contact point to find out whether there are not yet detected citizen engagement activities already happening that could be built upon for the topics to be discussed regarding IS implementation plans in the Basque hub.

4.4 Turkish Hub

The Turkish hub of the IS2H4C project is located in the Izmir-Manisa region, an important industrial region on the Turkish Aegean coast. The region is characterised by oil refineries and the production of household appliances, which provides ideal conditions for the use of waste and by-products as resources.

A particular focus of the hub is the capture and utilisation of CO_2 (CCU), which is captured from industrial processes and reused to produce e-methanol. In addition, the production of green hydrogen through electrolysis using renewable energies plays a central role. The combination of these technologies promotes a sustainable circular economy and contributes to the decarbonisation of industry.

4.4.1 Non-technological topics

Despite these promising technological approaches, there are numerous non-technological challenges that complicate the implementation of industrial symbiosis in the region. These include, in particular, regulatory uncertainties, economic barriers, social resistance and deficits in cooperation between industry and politics. The following section summarises the most important findings from the interviews.

a) Regulatory challenges

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A key obstacle to the implementation of industrial symbiosis in the Turkish hub are legal uncertainties and lengthy approval processes. Companies such as TU-I1 and TU-I3 face the challenge of adapting to frequently changing legal regulations, particularly in the area of waste management and CO_2 utilisation (cf. TU-I1, TU-I3).

Another problem is the fragmentation of the regulatory landscape, which is particularly challenging for companies that want to produce according to European standards (cf. TU-I1). The length and complexity of approval procedures, especially for projects involving recycling and by-product utilisation, represents a major hurdle (cf. TU-P1).

To address these barriers, TU-P1 is working on the development of an industrial symbiosis governance model and policy proposals to simplify the regulatory framework (cf. TU-P1).

b) Economic factors

A key obstacle to the implementation of industrial symbiosis in the Turkish hub are legal uncertainties and lengthy approval processes. This is partly due to the lack of specific regulations, with only general targets and roadmaps issued by government institutions. As a result, companies such as TU-I1 and TU-I3 face the challenge of adapting to frequently changing legal conditions, especially in the area of waste management and CO_2 utilisation (cf. TU-I1, TU-I3).

Another problem is the uncertainty regarding *market* demand. Products such as e-methanol or recycled raw materials do not yet have a solid market position, which makes companies cautious in their investment decisions. In addition, rising energy prices have a negative impact on the economic feasibility of many IS projects (cf. TU-I3).

Many companies are addressing these economic challenges through long-term *collaborations* and increased R&D investments. They hope that technological advances will reduce the costs of raw material and energy production and thus create economically viable solutions in the long term (see TU-I1, TU-I2).

c) Social impact and acceptance issues

Another key obstacle to the implementation of industrial symbiosis is the social perception and acceptance of new technologies. Many companies report a lack of trust between stakeholders, particularly when it comes to the exchange of raw materials or waste products (cf. TU-P1, TU-I3).

This is particularly problematic in the area of recycling technologies, as many customers have concerns about the quality of recycled materials (cf. TU-I3). This scepticism regarding sustainable materials poses a challenge for market acceptance and inhibits the dissemination of industrial symbiosis (cf. TU-I3).

Furthermore, there is a lack of skilled workers with specific know-how in the field of sustainable production and recycling processes. Companies like Ravago see the need to develop new skills in their workforce in order to drive the transformation of industry (cf. TU-I1).

To strengthen social acceptance, organisations such as TU-P1 are focusing on awareness-raising campaigns, training measures and collaboration platforms to make the advantages of industrial symbiosis more transparent and build trust between stakeholders (cf. TU-P1).

d) Job creation and related topics in the Turkish hub

The Turkish hub is an industrialized port area in the Izmir-Manisa area at the Aegean coast containing oil and gas (Tüpras) and household appliances companies (Arcelik). Two to-be-demonstrated synergies are key:

- Green H_2 from electrolysis and CO_2 captured from oil refining, utilized in the production of e-methanol.

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- Captured CO_2 and e-methanol used in the production of carbamate, followed by non-isocyanate polyurethane (NIPU).

Several stakeholders were identified as being most relevant to these synergies (Ravago Petrochemicals, Polisan Chemistry, Kocaer Celik, Kimpur, Air Liquide, and the İzmir Institute of Technology). At this point, only marginal information was collected from them, and this work is still in-progress. Some early information from interviewing TU-I2 complemented by a representative from TU-I3, can be summarised as follows:

- Job titles are changing. 10 years from now, the occupations associated with the to-be-demonstrated synergies may have titles that are more specific to circular economy or production of green H_2; however, at this point the workers still have conventional titles such as mechanical or chemical engineers. In 10 years, this may be hydrogen or CCU engineers. Similarly, chemists may be called H_2 experts. Industry and academic partnerships may play a relevant role in defining future job titles and qualifications. Industry and academic partnerships may play a relevant role in defining future job titles and qualifications.
- Connecting industry's needs to universities and other education institutes is a key activity to ensure that the right matches are made, connecting supply and demand.

In general, in the Turkish industry, it is expected that blue collar jobs will move into automation. This is already moving fast, with some companies constructing automated factories. This is no different in the Turkish hub, although for some sectors (i.e., manufacturing consumer goods) this is much more relevant than in others (i.e., oil refining, extraction of natural resources).

4.4.2 Addressing key challenges of the Turkish Hub

The Turkish hub offers great potential for sustainable industrial transformation through the use of CO_2 (CCU), the production of green hydrogen, e-methanol and carbamate, followed by NIPU (non-isocyanate polyurethane). The combination of these technologies promotes a sustainable circular economy and contributes to the decarbonisation of industry. The IS2H4C Living Labs can make a central contribution to addressing the identified non-technological challenges. The aim is to reduce regulatory hurdles, minimise investment risks and strengthen trust between stakeholders. In the context of these issues, cooperative approaches are to be developed in the Living Labs to simplify approval procedures and align them with political goals in the long term. The governance model for Industrial Symbiosis currently being developed by the Izmir Development Agency (IZKA) is a promising approach to structuring regulatory processes and improving cooperation between industry and administration[14]. IZKA is working on legal regulations and incentive mechanisms to overcome risks and barriers in the implementation of IS. It has conducted comprehensive framework analyses in this area. It is also collaborating closely on a policy document aimed at a legislative proposal, specifically focusing on the Ministry of Environment's industrial synergy legal framework infrastructure. This work is crucial to creating a more resilient and sustainable system. It also focuses on issues such as raising awareness of stakeholders, developing a culture of cooperation, and simplifying legal frameworks through awareness and training activities.

The economic challenges arise primarily from high investment costs and uncertain market demand for products such as e-methanol and recycled raw materials. The Living Labs are designed not only to promote communication and cooperation between industry, research, and financial institutions, but also to create more transparency and support dialogue with society in order to reduce reservations about the environmental impacts and quality of sustainable materials, providing a platform for the various stakeholders to align their interests, develop joint strategies and establish sustainable cooperation.

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[14] The governance model developed by IZKA draws inspiration from the UK's National Industrial Symbiosis Programme (NISP). Early collaborations and awareness-raising efforts since 2018, as well as two pilot projects, informed a national four-year program launched in 2021 in partnership with UNDP and supported by the UK Prosperity Fund.

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The Turkish Hub can draw on existing initiatives such as Material Marketplace Turkey (operated by BCSD Turkey), which facilitates the exchange of waste and resources, and the IZKA Synergy Workshops, in which numerous companies have already participated. These platforms promote cooperation and provide a solid foundation for the work of the Living Labs.

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5. Conclusion and Outlook

This report highlights the central role of non-technological factors for the successful establishment of Hubs4circularity. While technological innovations provide an essential foundation, the long-term viability and implementation of industrial symbiosis and the circular economy depend to a large extent on economic, regulatory, social, and organisational conditions. Building on the stakeholder analysis from D3.1, the report examines which non-technological contributions the stakeholders make, and which external factors influence successful implementation.

To systematically analyse the non-technological aspects of H4C, a categorisation was developed based on existing scientific literature, using a targeted literature search. This framework encompasses the dimensions of Economy and markets, regional development and (inter-)organisational collaboration, Regulatory and political framework, Environmental effects, and the social dimension – benefits and challenges. These categories are based on established models such as the concept of EIPs and the PESTLE approach but have been expanded to include factors that are particularly relevant to the H4C concept. This approach enables a structured assessment of how various non-technological aspects interact with technological innovation in circular economy projects.

5.1 Key non-technological factors in implementing H4C

Analysis of the four hubs examined – Germany, the Netherlands, the Basque Country, and Turkey – reveals specific challenges and opportunities in implementing circular economy strategies. The findings for the four hubs are based on semi-structured expert interviews with relevant stakeholders conducted between November 2024 and January 2025.

In the German Hub, regulatory uncertainties are a major challenge for the implementation of SAF as a final product of the to-be-demonstrated synergies. While the ReFuelEU Aviation initiative promotes the demand for SAF, it also creates uncertainties, particularly due to the awaited review of ReFuelEU Aviation and fragmented regulations between EU member states. At the regional level, approval or permitting and licensing processes delay the construction of new plants. Economic hurdles also exist: the high production costs of SAF, the cautious demand from airlines and mineral oil companies, and the lack of financial security for investments are hindering market introduction. Furthermore, there are societal challenges. Higher flight ticket prices due to SAF could disadvantage certain population groups, and their resistance to the expansion of infrastructure for hydrogen and CO_2 transport (NIMBY effect) is to be expected. strengthening the regulatory framework to reduce regulatory uncertainty, while proactively addressing community concerns and optimising the infrastructure for the integration of hydrogen, electricity, and gas.

In the Dutch Hub, unclear legal requirements for the production, storage and distribution of hydrogen are a major obstacle to planning security. In addition, the legal framework is often subject to change or is interpreted inconsistently. Economic barriers exist primarily in the high costs of hydrogen production, which is not very competitive compared to fossil fuels. Furthermore, there are hardly any financial incentives or subsidies for industrial symbiosis projects, which discourages private investors. Infrastructure is another major challenge: the current grid capacity is insufficient to meet future energy needs. The integration of hydrogen, electricity and gas grids is associated with high costs and technical complexity. At the societal level, there are concerns about the safety of new technologies such as hydrogen. In addition, there is a lack of public awareness of the benefits of industrial symbiosis, while at the same time there is resistance to large-scale energy projects. In terms of organisation, a lack of coordination and unclear roles between stakeholders are problematic. The availability of skilled workers and training programmes for new energy technologies are also insufficient. At the same time, it is necessary to ensure that hydrogen production and energy system transformation are designed to be sustainable in order to avoid negative environmental impacts.

In the Basque Hub, high investment costs for the implementation of industrial symbiosis and the development of the necessary infrastructure for CCU, hydrogen production, CO_2 pipelines and grid upgrades represent a central challenge. High operating costs and the lack of economic incentives for companies also complicate implementation. Therefore, existing initiatives such as NZBISC, BH2C and

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DCARTECH are used to promote the exchange of experience and the development of viable business models. Regulatory inefficiencies also hinder implementation. Long approval processes and uncertainties about future regulations make planning and investment difficult. To counteract this, dialogue between public administrations and industry is being strengthened. Another problem is societal resistance to certain IS projects, particularly in the areas of waste management, CO_2 storage and renewable energies. Furthermore, there is little interaction between industry players and civil society, which makes it difficult to find solutions for societal acceptance. This deficit should be compensated for by increased transparency and awareness raising, public consultations and participation formats.

In the Turkish Hub, regulatory uncertainties are one of the biggest challenges for the implementation of industrial symbiosis. Constantly changing legal requirements and lengthy approval processes make it difficult to invest and plan projects. To counteract this, IZKA is developing a governance model for IS to simplify the regulatory framework. Economic challenges also represent a significant hurdle. High investment costs for new technologies and uncertainties in the markets for e-methanol and recycled raw materials are hindering the implementation of IS projects. Rising energy costs are also reducing the economic viability of such approaches. Social factors also play a role: there is a lack of trust between companies with regard to the exchange of by-products, and there are concerns about the quality of recycled materials. In addition, there is a shortage of skilled workers for sustainable production and recycling. These challenges are to be met with targeted awareness campaigns, training and cooperation platforms.

5.2 Shaping the Future of H4C

In parallel to the non-technological challenges identified in this report, the European Commission has recently presented a comprehensive strategy in the form of the Clean Industrial Deal, which responds to key economic, regulatory, and social challenges of the industrial transformation (European Commission, 2025). The initiative highlights the importance of financing, competitiveness and securing a skilled workforce as key factors for successful industrial decarbonisation and a CE – topics that are also of crucial relevance for the H4C. Planned measures such as the Industrial Decarbonisation Bank with a financial volume of 100 billion euros and new state aid guidelines should facilitate investment in sustainable industrial processes and thus reduce economic uncertainty. At the same time, the Clean Industrial Deal addresses the competitiveness of energy-intensive companies by reducing energy costs, simplifying regulatory processes, and providing targeted support for circular business models, which are particularly crucial for IS projects. In addition, a new education strategy is being introduced with the Union of Skills, which strengthens qualification programmes for green and digital technologies, while the Quality Jobs Roadmap is designed to ensure fair working conditions and social security in the transformation. These measures, developed at the European level, not only create a more stable framework for IS projects, but also provide concrete starting points for addressing key challenges for the H4C. In the coming years, it will be crucial to monitor how these political and financial impulses are implemented in the H4C regions and to identify synergies between local initiatives and European strategies.

While the Clean Industrial Deal is creating a framework at the European level to address key non-technological challenges of industrial symbiosis, the Living Labs developed in the IS2H4C project are designed to complement and implement these measures at the local level. Through direct exchange between stakeholders in the H4C, European initiatives can be adapted to specific regional circumstances and needs. The Living Labs thereby serve as platforms for exchange between industry, science, politics, and society and aim at discussing technological contributions in connection with non-technological aspects. While the individual hubs have already developed helpful strategies for tackling non-technological challenges, the Living Labs aim at building on these existing structures and networks to ensure the continuous involvement of relevant stakeholders, making use of adequate formats of dialogue and co-creation between the relevant stakeholders. Furthermore, the Living Labs are dedicated to lign the different dimensions which needs to be addressed for successful regional development strategies related to Hubs4Circularity (see Chapter 3.2).

The next steps are for the topics and approaches of the Living Labs to be derived from the analysis of Deliverable D3.2. The existing multi-stakeholder approaches will be taken into account. The process of

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setting up the Living Labs will be further specified at the upcoming WP3 meetings, with a focus on selecting topics, involving relevant stakeholders and support from the hub leaders. The first workshops are planned for the second half of 2025. In addition to and complementary to the Living Labs, stakeholder committees are also to be established. This has already been initiated in the Turkish hub in order to also integrate stakeholders who are not involved in IS2H4C as partner organisations[15]. Furthermore, indicators to measure stakeholder involvement will be developed as part of Task 3.3, based on the identified drivers, enablers, and barriers.

[15] Corresponding stakeholder committees are also planned in the German, Dutch and Basque hubs.

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Annex A:

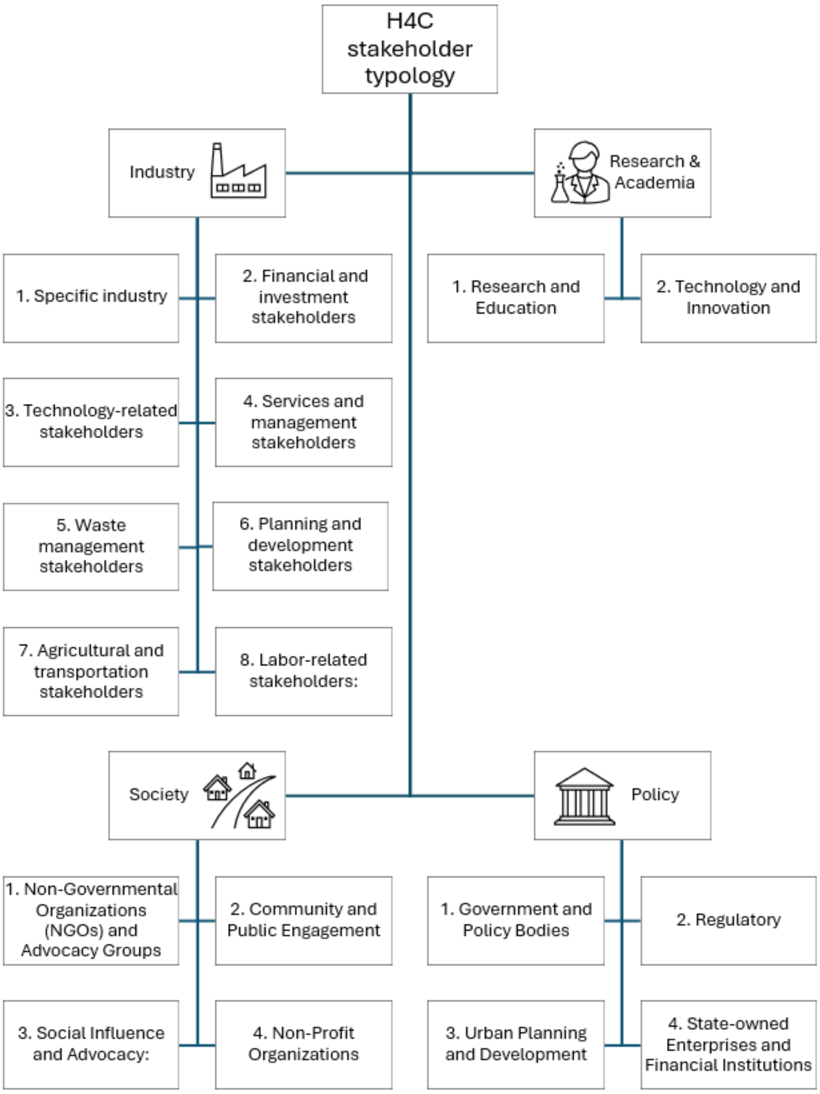

Figure 2: H4C Stakeholder Typology(Tleuken et al. 2025, in press)

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