Industrial Symbiosis^2 Hubs 4 Circularity

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Author(s):	Aidana Tleuken (UT), Patricia Rogetzer (UT), Michael Kohlgrueber (TUDO), Mathias Cuypers (TUDO), Clara Behrend (TUDO), Adrian Goetting (TUDO), Karina Maldonado-Mariscal (TUDO)
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Abstract

This deliverable D3.3 equips Hubs for Circularity (H4C) with a toolbox to measure their 'social glue' – the trust, alignment, and collaboration that drive circular transition. This deliverable of the IS2H4C project develops a structured approach to monitor and strengthen the non-technological foundations of H4C, focusing on stakeholder engagement and regional development. Recognising that technological innovations alone cannot deliver circularity, the report emphasises the central role of social relationships, trust, and collaboration across diverse stakeholder groups. Section 2 outlines the methodology for indicator development, combining literature review, stakeholder consultations, Social Network Analysis (SNA), and the Multi-Level Perspective (MLP). Section 3 translates validated drivers, barriers, and enablers (DBE) from previous deliverables into measurable indicators aligned with the Societal Readiness Level (SoReL) framework. These indicators are organised into thematic bundles and positioned along transition levels to support Living Lab implementation. Section 4 presents a consolidated overview of the selected indicators and introduces the use of SoReL scoring to track stakeholder progress and impact. Together, these tools enable hubs to assess and enhance their socio-economic contributions in alignment with regional strategies.

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Table of Content

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List of Tables

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List of Figures

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List of Abbreviations

AR	Augmented Reality
CE	Circular Economy
CO_2	Carbon Dioxide
DBE	Drivers, Barriers, Enablers
EU	European Union
GA	Grant Agreement
H4C	Hubs for Circularity
I/O	Input Output
ICC	Intelligent Cities Challenge
IoT	Internet of Things
IS	Industrial Symbiosis
IS2H4C	Industrial Symbiosis to Hubs for Circularity
LL	Living Labs
MLP	Multi-Level Perspective
MRIO	Multi-Regional Input-Output
NGOs	Non-Governmental Organisations
RIO	Regional Input-Output
SAF	Sustainable Aviation Fuel
SDGs	Sustainable Development Goals
SLR	Structured Literature Review
SMEs	Small and Medium Enterprises
SoReL	Societal Readiness Level
SNA	Social Network Analysis
VR	Virtual Reality

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1. Introduction

The Industrial Symbiosis to Hubs for Circularity (IS2H4C) initiative, funded by the European Union's (EU) Horizon Europe programme, seeks to accelerate the regional transition to a circular economy (CE) by turning conventional industrial zones into innovative Hubs for Circularity (H4C). By deploying advanced technologies such as carbon capture and electrolysis, the project aims to enhance resource efficiency, increase renewable energy use and minimise waste. At the same time, it aims to build resilient, inclusive ecosystems that connect businesses, governments, academia and local communities. IS2H4C operates four hubs – in Germany, the Netherlands, Spain's Basque Country and Turkey. The project is supported by thirty-five partners, all working to deliver scalable solutions that fit Europe's wider sustainability agenda (IS2H4C Project, 2024).

Technologies alone do not deliver circularity, as success depends on the quality of the relationships between companies, citizens, authorities and researchers. Therefore, circularity cannot be achieved with technology alone; social relationships and stakeholders are fundamental to implementation and collaboration to create feelings of inclusion, shared purpose and trust (Ashton, 2008). These are conditions that motivate long-term collaboration. High stakeholder engagement predicts smoother information flows, faster permitting and fairer benefit sharing (Azevedo et al., 2021; Erceg & Krzeminski, 2024). Conversely, weak engagement can stall promising technologies in bureaucracy or local opposition. Therefore, measuring engagement and the broader, non-technological impacts becomes essential (Fraccascia & Giannoccaro, 2020).

By connecting stakeholder engagement data, social-network analysis (SNA) insights, societal readiness level (SoReL) scoring and regional impact modelling, this Deliverable D3.3 provides a basis for and outlook to monitoring these indicators during Living Labs (LL). In these LL we highlight where further effort is needed. The deliverable transforms the qualitative and quantitative evidence gathered across work-package subtasks (such as non-technological challenges development, stakeholder analysis, SNA, regional input-output (RIO) models, LL) into a narrative that shows why, and how, the H4C partners can deepen collaboration and deliver tangible regional value.

The steps we follow to build this deliverable were: a) to give an introduction into the objectives and scope of the deliverable building on the previous tasks and deliverables (D3.1 and D3.2); b) to explain the methodology used for this deliverable; c) to develop indicators with the help of this methodology; and d) show how the selected, developed indicators could be applied in one of the project's hubs. These steps build the four chapters presented here. The first chapter is the introduction to the deliverable. The second chapter shows the methodology used (approach). The third chapter applies the methodology to come up with a list of indicators. Finally, the fourth chapter gives an outlook on how we continue with ongoing tasks in our work package 3 and introduces the next steps.

This Deliverable D3.3 addresses the following question: *How can the hubs monitor and strengthen the non-technological foundations that are based on stakeholder relationships and engagement of stakeholders into H4C?* To answer, the report draws on earlier project outputs and outlooks for the task T3.3 (*Development of socio-economic indicators to measure regional impact of hubs*). This Deliverable D3.3 is structured into four parts, which are described below. The first four parts show the different steps taken for the selection of indicators, whereas the next steps relating to T3.3 (SNA and RIO) are presented as an outlook.

First, we compile the extensive catalogue of drivers, barriers and enablers (DBE), which are assembled in Deliverables D3.1 (*Map of stakeholders and their interests/needs*) and D3.2 (*Methodology for assessment of non-technological topics*) and converted them into a toolbox of qualitative and quantitative indicators (see Section 3 of this document).

Second, we subset the broad-range indicators (derived from the DBE in Step 1) mapping each indicator onto two non-technological challenge domains that have been already validated for the four hubs in the previous Deliverable D3.2. Given the scope of Deliverable D3.3., we focused on two non-technological topics: *stakeholder engagement* and *regional development* as indicated in the Grant Agreement (GA). We also show how the indicator bundles are aggregated into a baseline SoReL score for the hubs.

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Retaining the nine-stage scale – SoReL 1 for problem recognition up to SoReL 9 for proven societal uptake (Bruno et al., 2020) – we then plan to adapt each stage into the H4C context. It is combined with an outlook on the preliminary SNA, which gives an idea how we show several perspectives (e.g. resource flow, communication flow, etc.) in the H4C network (for details we refer to the working paper by Tleuken et al., 2025b).

Third, we use the Multi-Level Perspective (MLP) to narrow down the indicators from Steps 1 and 2 and identify the 'niche' ones that can further be taken up, discussed and used in Living Labs.

Fourth, since stakeholder engagement should been measurably beneficial for other stakeholders, we introduce an outlook on regional socio-economic indicators. The quantification of these indicators will be delivered through regional and multi-regional input-output (MRIO) modelling in T3.4 (to be discussed in Section 4.3 of this deliverable). Simulating “with- versus without-H4C” scenarios will show how stronger engagement and higher SoReL scores ripple through the regional economy, aligning hub activities with local regional strategies and giving authorities and citizens a direct stake in the venture.

1.1 Objectives

The main objectives of this Deliverable D3.3 correspond to the socio-economic H4C development. The first objective is to consolidate the socio-economic stakeholder engagement measurement on which industrial-urban symbiosis depends. The second objective is to ensure that this enhanced collaboration generates regional value.

For the first objective, we want to equip each hub with a robust and practical monitoring system that can measure the social foundations of industrial-urban symbiosis in H4C which is represented by an increasing level of stakeholder engagement. To achieve this, we construct a set of qualitative and quantitative indicators that reflect the drivers, barriers, and enablers of engagement for different stakeholders identified in Deliverables D3.1 and D3.2. These indicators will be embedded within a SoReL framework (not part of this deliverable), enabling hubs to track, compare, and communicate their progress from early awareness to mainstream uptake. In parallel, we will conduct preliminary SNA to identify who occupies the core of hub collaboration, who remains at the periphery, and what relational gaps must be bridged to advance to the next SoReL stage. Importantly, LL participation can deliver several benefits to each stakeholder. For example, accelerated permitting, access to shared infrastructure or new commercial leads, so that the consortium partners can verify whether and how continued engagement is being rewarded.

For the second objective, the goal is to demonstrate that stronger stakeholder engagement leads to stronger measurable benefits for the regions. The deliverable will define an initial portfolio of socio-economic development indicators that could potentially align with regional strategies. It will also outline how these indicators will be quantified using regional and MRIO modelling in T3.3, enabling comparisons between scenarios with and without H4C. Finally, the deliverable will link changes in the engagement dashboard and corresponding advances in the SoReL framework to the anticipated macro-level impacts, thereby clarifying how non-technological progress within the hubs can enhance employment, regional competitiveness, and environmental quality.

1.2 Scope and Definitions

The analytical scope of this deliverable is confined to the non-technological conditions that impact H4C implementation and to the stakeholder relationships through which those conditions are shaped. Stakeholders are grouped into the four macro-types (depicted in Figure 1): Industry, Research & Academia, Society, and Policy. Each macro-type comprises several functional sub-classes (e.g., financial investors, waste-management firms, community organisations, regulatory bodies); their full mapping and interests have been documented in Deliverable D3.1. Throughout this report the term stakeholder

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engagement denotes the spectrum of interactions, including informational, financial, contractual, or resource-sharing.

Non-technological impacts are delineated according to the five thematic domains synthesised in Figure 2 and analysed in depth in Deliverable D3.2: economy and markets; regional development and (inter-) organisational collaboration; regulatory and political framework; societal benefits and challenges; and environmental effects. The present deliverable tracks how stakeholder engagement influences performance across two domains (stakeholder engagement and regional development) and, conversely, how barriers or enablers within each domain feed back into engagement dynamics. Technological performance indicators (e.g., process yields, energy efficiency) are expressly excluded except where they intersect with the social or institutional issues under investigation.

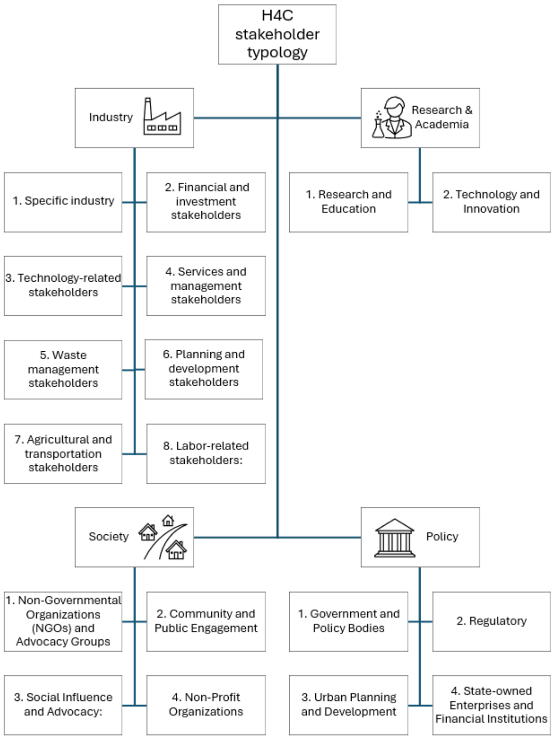

Figure 1: H4C Stakeholder typology
(Source: Tleuken et al., 2025a)

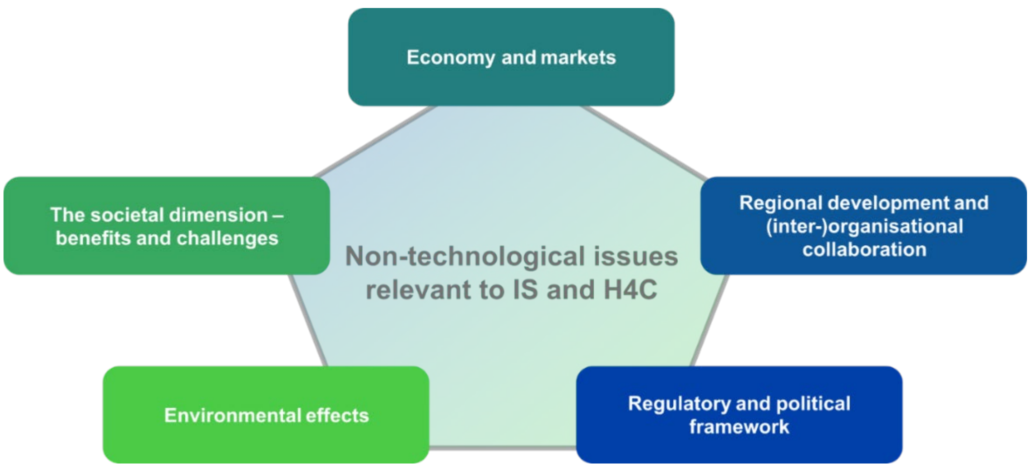

Figure 2: Non-technological issues relevant to IS and H4C
(Source: Deliverable D3.2)

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2. Methodology

This chapter outlines the methodology for developing indicators to measure stakeholder engagement in the IS2H4C project. Drawing on a structured literature review and prior work (Section 2.1), key barriers, enablers, and drivers are translated into measurable success factors aligned with the Sustainable Development Goals (SDGs). SNA (Section 2.2) and stakeholder consultations during the general assembly (Section 2.3) provided further insights into stakeholder relationships and engagement practices. The MLP (Section 2.4) is applied to contextualize these dynamics within broader transition processes. Finally, a stepwise procedure (Section 2.5) guides the development of socio-economic indicators focused on non-technological impact, particularly at the niche level relevant for LL.

2.1 Methodology of development of indicators for stakeholder engagement

Based on the Structured Literature Review (SLR) of numerous factors influencing stakeholder engagement within the context of Industrial Symbiosis (IS), which was extensively discussed in Deliverable 3.2, we identified and synthesized multiple barriers, enablers, and drivers relevant to the field.

Following the initial automated alignment, a comprehensive manual review and refinement were carried out by the authors to enhance the precision and relevance of the results. This iterative process facilitated the translation of identified barriers, enablers, and drivers into clear, actionable success factors along with corresponding measurable indicators. Specifically, we categorised these DBE into neutral-sentiment factors, ensuring objectivity and broad applicability, thereby allowing them to effectively serve as robust indicators of success.

Moreover, aligning the derived success factors and indicators with the SDGs (for details see FRONTIER framework by Tleuken et al., 2025a) explicitly demonstrates how effective stakeholder engagement within H4C initiatives contributes with broader sustainability and CE objectives. This SDGs alignment not only validates stakeholder engagement practices in urban-industrial and rural IS contexts but also reinforces their potential contribution to achieving global sustainability targets.

2.2 Social Network Analysis

The SNA employed in this deliverable draws on the resource-exchange relationships specified in the IS2H4C Grant Agreement, which already identifies material, energy, information and service flows envisaged between consortium partners. These predefined links were extracted, coded into an adjacency matrix and visualised, producing a baseline graph for each of the four hubs. The resulting indicators fulfil two functions in the present study. First, they feed directly into the engagement dashboard in Section 3, offering a quantitative complement to the qualitative DBE. Second, they serve as objective evidence for the SoReL assessment: a hub can claim progression only if the minimum cohesion and cross-sector connectivity implied by its next SoReL stage are reflected in the network.

2.3 Stakeholder consultations

During a workshop held on 20th February 2025 in Istanbul, as part of the 3rd general assembly of the IS2H4C project, we specifically collected data on stakeholder relationship practices and interactions. The general assembly served as an ideal platform for this data collection effort, as it gathered representatives from all project partners. Consequently, the resulting dataset provides a comprehensive and representative snapshot of the diverse stakeholder landscape involved in the H4C project. The inclusive nature of the workshop enabled participants from varied backgrounds (including businesses, governmental agencies, local communities, and research institutions) to share their opinions and communicate openly about their experiences regarding the IS and H4C engagement. The discussions and interactions captured during the event highlighted various network patterns, such as, communication, monetary flow, and regulatory relationship.

An IS2H4C workshop titled "Industrial-Urban Symbiosis" was conducted on 21st February 2025 as part of the general assembly in Istanbul. A total of 20 participants attended the event, providing a diverse

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and representative sample (with a balanced representation of genders) from various stakeholder groups, involved in the IS2H4C project. Following the workshop, a comprehensive questionnaire was distributed to project partners to gain deeper understanding into their experiences, perspectives, and perceived barriers, enablers, and drivers related to engagement in H4C and IS in general. Stakeholders who responded to the questionnaire included representatives from industry, research, community organizations, and policy institutions. Participants evaluated institutional, spatial, socio-economic, technological, and regulatory barriers, enablers, and drivers affecting their engagement in H4C. This detailed feedback obtained through the survey provides understanding into ranking of DBE in H4C engagement, guiding future strategic interventions and supportive mechanisms to develop successful and sustainable industrial-urban symbiosis within the IS2H4C project.

2.4 Multi-Level Perspective on H4C

The MLP provides a comprehensive framework for analysing sustainability transitions within socio-technical systems. It conceptualizes transitions across three interconnected layers: the landscape, regime, and niche (Geels, 2002; Geels & Schot, 2007). Applying MLP to IS and H4C allows a deeper understanding of how circular economy initiatives evolve, scale, and ultimately influence mainstream practices.

At the landscape level, broader societal, environmental, and economic trends exert pressures that stimulate change within existing industrial systems. For example, H4C are fundamentally shaped by macro-level drivers such as climate change mitigation policies, international resource scarcity, and geopolitical developments affecting energy security (Mendez Alva, De Boever, & Van Eetvelde, 2021). The German hub, specifically, operates in a landscape strongly influenced by EU decarbonization policies and national commitments to climate neutrality, while the Turkish hub is shaped by factors such as demographic pressures and energy dependency.

The regime level represents the dominant industrial practices, infrastructure, regulations, and norms that maintain stability but often resist transformative change (Geels & Schot, 2007). Regime-level barriers frequently encountered within H4C include fragmented or conflicting regulations, lengthy permitting processes, and institutional inertia (Laatsit & Johansson, 2025). The Dutch hub, for instance, exemplifies these regime challenges through complicated permitting structures and fragmented energy regulations. Similarly, the Basque hub experiences bureaucratic inertia and conflicting land-use policies, illustrating how regime resistance can impede circularity innovations (Susur, Hidalgo, & Chiaroni, 2019).

At the niche level, innovative solutions and new socio-technical models are developed and tested in protected spaces. LL within H4C embody niche-level experimentation, facilitating co-creation processes among stakeholders to prototype circular solutions and confront societal acceptance issues (Bouwma et al., 2022). The LL in each of the four hubs plan to actively engage local communities to address public resistance, transforming societal engagement into a critical innovation pathway. Thus, it is planned to connect municipalities, industry, and communities to pilot CE solutions, developing solutions on how niche practices can gradually influence broader regimes. LL are claimed to be a relevant approach for such activities (Tyl & Allais, 2021).

Framing H4Cs within an MLP highlights the essential role of niches as innovation incubators, regimes as barriers or enablers, and the landscape as a broader contextual driver of change. Recognizing the interactions among these levels and explicitly channelling the resulting MLP-scoped insights into LL co-creation cycles and cross-hub expert panels is critical for developing strategies that facilitate the transition from niche experiments to regime transformations. Consequently, LL and H4Cs will test both hub-specific solutions, and, in general, contribute to the systemic changes necessary for sustainable industrial transitions (Susur et al., 2019; Bouwma et al., 2022).

Since the breakthrough of new solutions depends on the interaction of different levels (according to MLP) there are corresponding levels of trust within H4C and IS networks that align with these structural layers. At the landscape level, societal trust relates to broad cultural attitudes, macro-institutional confidence, and deep-seated societal norms that shape general expectations about trustworthiness and

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cooperation (Leder et al., 2023). At the regime level, institutional trust corresponds to confidence in established organizational structures, dominant regulatory frameworks, and standardised inter-organisational relationships that characterise the socio-technical interaction (Ramsheva et al., 2019). At the niche level, interpersonal trust emerges through direct relationships between individual actors, managers, and facilitators who collaborate in protected spaces of innovation, often developing through repeated interactions and shared experimental norms (Ashton & Bain, 2012).

We plan to apply the MLP categorisation for the indicators developed in this deliverable. Thus, we could scope niche-level indicators, on which we could focus during future Living Labs.

2.5 Procedure of socio-economic indicators development for non-technological impact

The procedure of scoping socio-economic indicators for non-technological impact that could be impacted through further actions of LL, while not being too broad on decision-level, we follow the following procedure which is described in Figure 3. Step 1 involves the identification of DBE that influence socio-technical transitions. This foundational step sets the stage for indicator development and is described in Section 3.1. In Step 2, broad-range indicators are derived from the previously identified DBE. This step ensures a comprehensive set of potential indicators rooted in the contextual factors identified earlier. The details of this step are provided in Section 3.3. Step 3 scopes the indicators specifically toward non-technological topics, with a focus on the “societal dimension” and “regional development.” (as a subset of indicators presented in Section 3.2). This thematic refinement helps align the indicators with broader socio-economic and cultural considerations. The result for this step is described in Section 3.4. Step 4 introduces segmentation of the non-technological indicators according to the MLP, focusing on the “niche” level. At this stage, relevant niche-level indicators are selected based on their applicability and significance within specific innovation contexts. This process is explained in Section 3.5. Finally, Step 5 involves the operationalization of the niche non-technological indicators, distinguishing between cross-hub and hub-specific indicators. The final list of cross-hub indicators is presented in Section 3.6. An outlook on how to proceed with hub-specific indicators is given on the example of the Dutch hub.

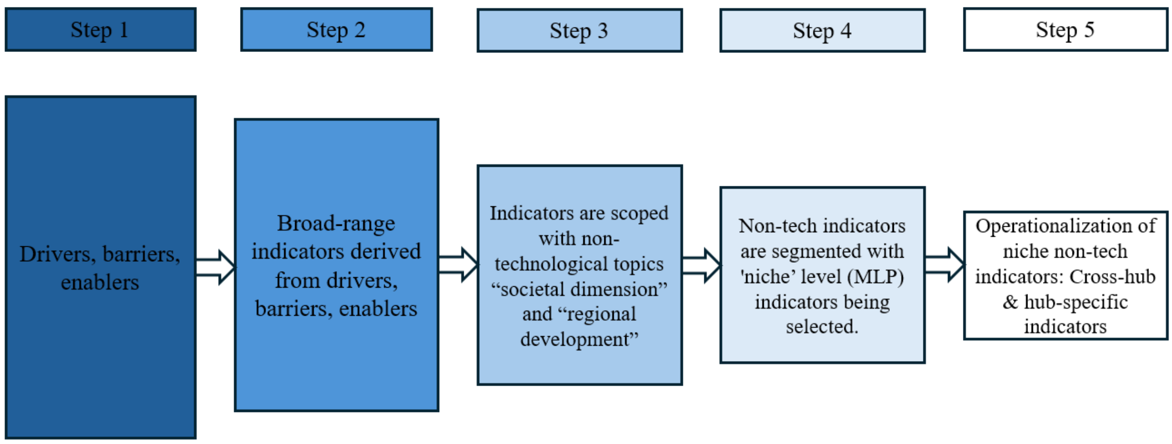

Figure 3: Procedure of development of socio-economic indicators with non-technological impact

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3. Development of Socio-Economic Indicators

This section is structured as follows. First, some general indicators to measure stakeholder engagement and regional impact (guided by the SoReL, are shown. Then, we follow the five steps of the procedure for developing socio-economic indicators with non-technological impact (as indicated in Section 2.5). First, we distil the extensive list of DBE that determine how stakeholders engage with H4C (Section 3.2). Second, we report the findings of the validation workshop we conducted during the General Assembly in Istanbul (Section 3.3), where project partners scored the relative weight of those factors. Third, the validated items are consolidated into an organized set of measurable indicators (Section 3.4). Fourth, these indicators are assigned to the project's two priority non-technological themes – (i) the societal dimension, and (ii) regional development & inter-organisational collaboration – creating a coherent engagement dashboard (Section 3.5). Finally, the indicators are positioned along the MLP (niche, regime, landscape) to spotlight the levers that the consortium can influence most directly through Living Lab activities during the current project phase (Section 3.6). Then criteria for the selection of indicators are developed (Section 3.7), and selected indicators are then operationalised (Section 3.8). As an example, the procedure for some indicators is shown exemplarily for the Dutch hub (Section 3.9).

3.1 General indicators to measure **stakeholder engagement** and **regional impact**

Stakeholder engagement will be measured by the **Societal Readiness Level (SoReL)**. The SoReL serves an indicator, offering a *consolidated measure* of **stakeholder engagement**. Its primary role is to aggregate a wide array of data collected through the Living Labs into a single, comprehensible score. Combined into a SoReL score, they can form a metric that communicates progress from concept to implementation. This is useful for a broad range of stakeholders, including hub managers and regional authorities. SoReL functions as an indicator that synthesises the full scope of the stakeholder engagement dashboard into one unified representation of regional transition.

Outlook on the further procedure in Task T3.3 regarding SoReL: The process of constructing the SoReL score in IS2H4C is tailored to the context of the H4C. First, the project adopts the established nine-stage SoReL model (ranging from Level 1: problem recognised, to Level 9: solution fully accepted, see Figure 4 for an overview, highlighting the role of stakeholders in this progress), but adapts each stage with H4C-specific definitions. In the context of H4C, the nine SoReL levels can be interpreted as a progressive pathway from early awareness of CE to the point at which hub operations are fully embedded in regional practice. SoReL 1 is reached when regional stakeholders publicly acknowledge linear-economy pressures, such as waste heat, carbon dioxide (CO_2) emissions or material losses, and recognise that an H4C could address decarbonization goals. At SoReL 2 the problem context is analysed in detail: a first hub vision is drafted, key companies, authorities, researchers and community organisations are listed, and preliminary resource-exchange ideas are scoped. SoReL 3 is achieved once that vision becomes a concrete solution, For example, a draft business and governance model is produced and anchor actors sign expressions of interest. The transition to SoReL 4 involves real experimentation of resource symbiosis pilot operation. When independent experts validate the technical and socio-economic benefits of that pilot and policy or financial stakeholders support a scale-up plan, the hub attains SoReL 5. SoReL 6 corresponds to a full demonstration in a real setting. Thus, LL integrate stakeholder consultations, where trust levels are registered, and a baseline MRIO assessment shows net-positive local jobs and value added. At SoReL 7 the solution is refined and up-scaled. Regulatory or logistical bottlenecks are solved, hub governance is formalised and even additional firms join the exchange, an evolution which can be reflected in increased social network density. SoReL 8 denotes societal integration. Circular business models could operate commercially, regional skills programmes train the required workforce, and local planning and procurement rules embed H4C objectives. Finally, SoReL 9 is reached when the hub is recognised in regional development and climate-neutrality strategies, the majority of targeted resource flows circulate through hub infrastructure, long-term monitoring confirms sustained socio-economic and environmental gains, and the initiative enjoys broad public endorsement as standard practice.

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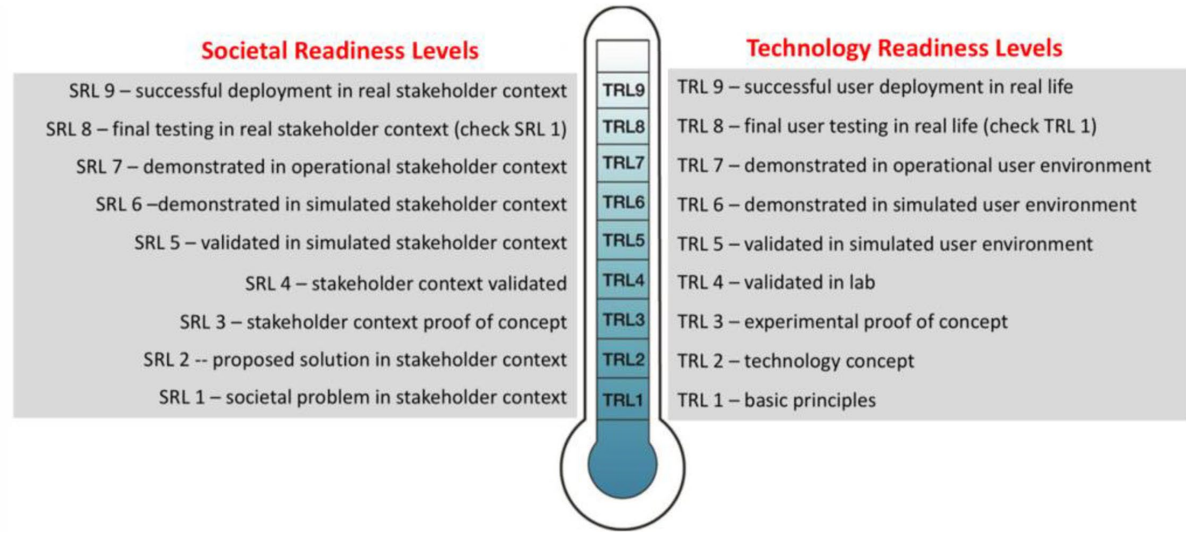

Figure 4: Evolvement of SoReL scores
(Source: Innovation Fund Denmark, 2019)

The scoring logic groups these indicators into five non-technological themes: Regulatory, Economic, Infrastructure, Societal, and Organisational (see Figure 2). Verification of each hub's claimed progress can take place bi-annually through LL reports and external reviews conducted during general assembly meetings of the project.

As sub-indicators we use then use the different levels of SoReL and translate them into (mostly qualitative) indicators (such as new solution tested with an amount of stakeholders from different categories).

Stakeholder engagement:

- **numbers of stakeholders involved** in the hubs
- **categories of stakeholders (including the gender dimension)** covered by the living labs (referring to our four main groups/types of stakeholders, see Figure 1)
- **frequency of workshops** (to get a trackable impression of stakeholder engagement over the project duration)

When it comes to the *value for stakeholders*, we want to measure how the identified non-technological key challenges (from Deliverable D3.2) are addressed. This should be seen as a first approach which will be adjusted hub-specifically, such as the Local Green Deals in the Dutch hub (see more in Section 3.9). This as an approach to quantify and to describe qualitatively.

Regional impact:

- **Indicators from Input-Output (I/O) models:** Indicators that provide insights into the flow of goods and services within an economy, revealing inter-industry relationships.
  - Environmental indicators (e.g. regional impact on CO_2 emissions, energy use)
  - Socio-economic indicators (e.g. regional impact on job creation)

3.2 Drivers, Barriers, and Enablers for *Stakeholder Engagement*

Barriers:

Top barriers in the institutional and organizational categories include uncertainty, physical resource (e.g., waste, by-products) availability, and information dissemination. Uncertainty, resulting from deficient planning and inadequate risk mitigation techniques, poses significant obstacles to successful stakeholder engagement. This is especially the case when identifying system boundaries and defining processes. Additionally, discontinuity of actions and reliance on emerging technologies may introduce unmanaged risks. Operational challenges in resource availability are also crucial. Issues include

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insufficient quality or quantity of waste, requiring experienced labour for proper treatment. Dependence on specific technologies for by-product exchanges may limit available options. Furthermore, the diverse composition of industrial wastes discourages potential trade, and certain materials cannot currently be treated due to resource constraints. Small and medium enterprises (SMEs) may lack internal resources necessary for sustainable transitions, while cooperative efforts to overcome these barriers can be hindered by trust and confidentiality issues. Information dissemination poses another significant barrier. Limited institutions and mechanisms for sharing data on waste supply and utilization impede the development of IS. The absence of environmental quality monitoring data further restricts information available to local communities.

Spatial barriers contribute to transportation issues, negatively impacting industrial efficiency and increasing costs. Factors such as facility distances, geographic range, and local traffic conditions can either facilitate or hinder productivity. Additionally, spatial regulatory policies, including zoning laws, region-specific building codes, and variations in economic policies, further restrict technological innovation.

Socio-economic barriers include collaboration, technological readiness, financing, and the profitability of CE practices. Collaboration is critical for CE and IS, yet several factors hinder its effectiveness. Societal passivity and insufficient administrative support undermine collaborative efforts, while industrial plants may resist structural changes. Conflicting interests and mistrust among stakeholders further restrict cooperation and knowledge exchange.

Financing barriers include high investment requirements and a lack of external and national financial support. High costs associated with waste treatment technologies often surpass the financial benefits, complicating profitability. Moreover, achieving sustainability may conflict with maximizing profits, especially in scenarios involving costly energy retrofitting in heritage areas or the production of local, ecologically sound products.

Technological readiness presents specific challenges to stakeholder engagement. Limited availability of customized software and inadequate usability of immersive technologies restrict effective participation. Existing infrastructure and software often lack the versatility needed for qualitative risk management, adaptive modelling, and scenario analysis, which leads to inaccuracies in modelling and simulation. Yet, technological readiness can present both an enabler and a barrier in some cases simultaneously. For example, The ReFuelEU Aviation (German Hub) – this regulation drives sustainable aviation fuel (SAF) production (by mandatory blending rates for SAF), but at the same time it creates regulatory uncertainty (due to the revision in 2027).

Regulatory barriers primarily result from inadequate policies, excessive bureaucracy, and insufficient incentives. Current regulations frequently favour linear economy practices, while the absence of carbon penalties and insufficient regulation in the remanufacturing sector create additional hurdles. Policies explicitly promoting symbiotic exchanges and IS initiatives are notably absent, while public procurement laws and product authorization rules add further complexity. Bureaucratic processes significantly delay and complicate CE initiative implementation, and overlapping authorities with contradictory regulations further challenge remanufacturing efforts. Moreover, the lack of robust incentivizing policies, such as tax relief, coupled with inadequate environmental legislation enforcement, results in poorly managed industrial wastes, including hazardous materials.

Table 2: Barriers for stakeholder engagement

Barriers			
Institutional and Organizational	*Spatial*	*Socio-economical and technological*	*Regulatory*
Uncertainty: Deficient planning, lack of risk mitigation, discontinuity of actions	Transportation issues: Distance between facilities, local traffic, geographic range	Collaboration: Passive engagement, lack of administrative support, clash of interests, trust issues	Regulation policies: Favor linear economies, lack of carbon penalization, unregulated remanufacturing

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Resource availability: Insufficient waste, lack of experienced labour, SME limitations	Spatial regulatory policies: Zoning laws, region-specific building codes, economic policy variations	Financing: High investments, lack of external/national financial support, costly waste treatment technologies	Bureaucracy: Delays in implementation, overlapping authorities, contradictory regulations
Information: Limited data-sharing mechanisms, lack of environmental monitoring data		Profitability: Conflict between sustainability and profit, high costs of eco-products, energy retrofitting	
		Technological readiness: Limitations of software, lack of versatile models for risk management, simulation	

Enablers:

Institutional and organizational enablers for effective H4C stakeholder engagement include factors such as coordination, business model alignment with CE, and expertise. These factors are essential for all stakeholders. Effective alignment of business models with CE involves several key components, including robust inventory management, long-term practice-based circular strategies, and the development of entire value chains. These elements ensure that a company's ethical practices align with sustainable goals. Additionally, matching consumers with remanufacturing services promotes reuse and extends product life cycles. Effective coordination requires clearly defining roles and responsibilities and necessitates an organizational structure that supports the adoption of CE strategies across various stakeholders, including logistical synchronization. The role of a facilitator is crucial as it fosters trust, facilitates knowledge exchange, and initiates discussions about IS. Existing organizational relationships can provide a foundation for IS. Moreover, building expertise through training, educational programs, and the development of a strong resource pool is vital for enabling effective IS.

Spatial enablers focus solely on feasibility factors, including the proximity and geographic concentration of various industries and the availability of sufficient space for infrastructure installation.

The socio-economic and technological category includes technological readiness, collaboration, and awareness – factors relevant to all stakeholders. Technological readiness involves indicators reflecting an organization's capacity to integrate and utilize advanced technologies to enhance stakeholder engagement and operational efficiency. Collaborative design platforms, Virtual Reality (VR), Augmented Reality (AR), and suitable software improve decision-making processes and engagement. Innovative technologies for IS infrastructure, such as real-time monitoring, prefabricated building solutions, Internet of Things (IoT), big data, automation, and optimization, significantly contribute to efficiency and sustainability. Staying abreast of technological advancements is crucial for maintaining competitive and sustainable industrial practices. Other essential socio-economic enablers include awareness and values aligned with CE goals. These factors encompass social responsibility, commitment to sustainability, and consumer preferences for local products, which collectively drive sustainable stakeholder engagement.

Regulatory enablers include regulatory policies and incentivising policies. Incentivising policies aim to foster sustainable practices through improved policy frameworks and financial incentives, such as tax reductions and interest-free loans. Regulatory policies significantly enable sustainable industrial practices, especially for H4C, by establishing technical guidelines for IS and sustainable waste management. Ensuring effective implementation of laws and compliance is fundamental. Overall, adaptive and simplified regulatory frameworks are necessary to support the efficient application of sustainable practices.

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Table 3: Enablers for stakeholder engagement

Enablers			
Institutional and Organizational	*Spatial*	*Socio-economical and technological*	*Regulatory*
Business model alignment: Inventory management, circular strategies, value chains	Nearby geographic location of industries	Technological readiness: Collaborative platforms, real-time monitoring, IoT, prefabrication, automation	Incentivizing policies: Tax reduction, interest-free loans, favourable policy frameworks
Coordination: Clear delineation of roles, facilitator role, knowledge exchange, trust-building	Sufficient space for infrastructure	Social responsibility, consumer choice towards local products, sustainability commitment	Regulatory policies: Technical guidelines for IS, sustainable waste management, legal compliance
Expertise development: Training, educational programs, resource pool development			

Drivers:

Institutional and organizational drivers include key factors such as collaboration, alignment of business models with CE principles, and measurement of effectiveness. Alignment with CE, as a driver, means intrinsic motivation of the whole stakeholder network to follow sustainable consumption and production, which drives the process towards CE. While raising this awareness is essential for enabling IS, developing a sense of environmental and social responsibility is crucial to actively promote it. Effective collaboration requires an integrated network of diverse stakeholders, accounting for their varying interests and the increasing number of stakeholder types. This inclusive approach is crucial for the success of CE initiatives. Aligning business models with CE principles involves adopting Circular Business Models such as peer-to-peer exchanges, prosumer concepts, and energy community formation. These models enhance sustainability and economic viability. Measuring the effectiveness of CE initiatives through key performance indicators is essential, allowing continuous evaluation and improvement of strategies.

The spatial dimension plays a critical role in driving IS cooperation. A significant driver is decentralisation of energy manufacturing, supporting local production and consumption. Early planning for optimal waste infrastructure locations ensures strategic placement, maximizing efficiency and minimizing environmental impacts. Geographic proximity of industries is essential for reducing transportation costs and environmental impacts, facilitating easier and more cost-effective exchange of resources. Additionally, proximity to large metropolitan areas can enhance IS cooperation by increasing stakeholder diversity and participation opportunities.

Socio-economic and technological factors significantly drive IS, including alignment with CE values, economic profitability, and technological readiness. CE-aligned values primarily involve environmental consciousness. Increasing awareness is necessary, yet developing environmental and social responsibility is equally crucial for driving IS. The growing demand for cleaner and safer environments supports alignment with CE principles, enhancing business visibility, social identity, moral culture, and corporate social responsibility. Evolving consumer expectations, social media influence, and community interest in environmental benefits further bolster these values.

Economic benefits are a major incentive for businesses participating in CE initiatives, such as cost savings that enhance self-sufficiency, reduce national energy import dependence, and improve energy security. Availability of cost-effective, reliable energy sources sustains these economic advantages. Successful CE implementation depends on technological readiness and advanced technology integration. Key technological enablers include data-driven design, integrated information systems, and blockchain-based tracking systems. The increased adoption of smart technologies enhances data management, optimizes processes, and improves transparency, critical factors in successful CE initiatives.

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Regulatory frameworks significantly drive IS and CE initiatives. Supportive regulation policies prioritize and enforce IS through mechanisms such as audits and heavy fines. Studies emphasize strict enforcement as essential for adherence and driving progress. While incentives have helped establish IS environments, stricter regulations are required for sustained progress. Incentive-based policies, including financial and non-financial rewards, strongly encourage businesses to adopt CE practices. Solid financial support mechanisms, providing necessary resources, are particularly effective for sustaining CE adoption and practices.

Table 4: Drivers for stakeholder engagement

Drivers			
Institutional and Organizational	*Spatial*	*Socio-economical and technological*	*Regulatory*
Collaboration through an integrated network of diverse stakeholders	Decentralization of energy manufacturing supporting local production and consumption	Values aligned with CE: environmental and social responsibility, consumer awareness	Enforcement through audits and fines
Business model alignment within CE: Circular Business Models, peer-to-peer exchanges, energy communities	Early planning of waste infrastructure location to optimize efficiency	Economic profitability through cost savings, reduced reliance on energy imports	Incentive mechanisms
Measurement of effectiveness through KPIs	Geographic proximity of industries, proximity to metropolitan areas		

3.3 Validation of Barriers and Enablers

To validate the barriers and enablers identified in the literature review, we conducted a stakeholder workshop aimed at assessing the relevance and perceived impact of these factors in practice. Participants were invited from diverse backgrounds to ensure a comprehensive evaluation. As shown in Figure 5, the majority of respondents came from academic and industrial sectors, providing valuable insights from research and practical implementation standpoints. The workshop was attended by 20 participants representing diverse stakeholder groups (Figure 5). Participants were recruited from two sources: consortium partners involved in the project and invited external stakeholders (representatives of universities and industries) with expertise in industrial-urban symbiosis. Event was called “Pathways to Industrial-Urban Symbiosis”. Event was announced through the network of project partners and also through the web-channel of Linkedin page[1]. The workshop was conducted on February 20th as part of a broader event focused on industrial-urban symbiosis. It was complemented by group discussion, were panelists and attendees discussed together barriers and enablers. The participant distribution included representatives from academia and research (41%, n=7), industry (35%, n=6), community and NGOs (18%, n=3), and policy/regulatory bodies (6%, n=1), with three participants not specifying their category.. There were 8 males, 6 females, and 6 individuals with unknown gender. The representation from policymakers was relatively limited, highlighting a potential gap in policy-related perspectives that may warrant further engagement in future studies.

[1] https://www.linkedin.com/posts/is2h4c_is2h4c-circulareconomy-industrialsymbiosis-activity-7295009671122227200-ATnM?utm_source=share&utm_medium=member_desktop&rcm=ACoAAB1-O2IBHFgj6oOsjKdy2NjE5ep_uODEWDI

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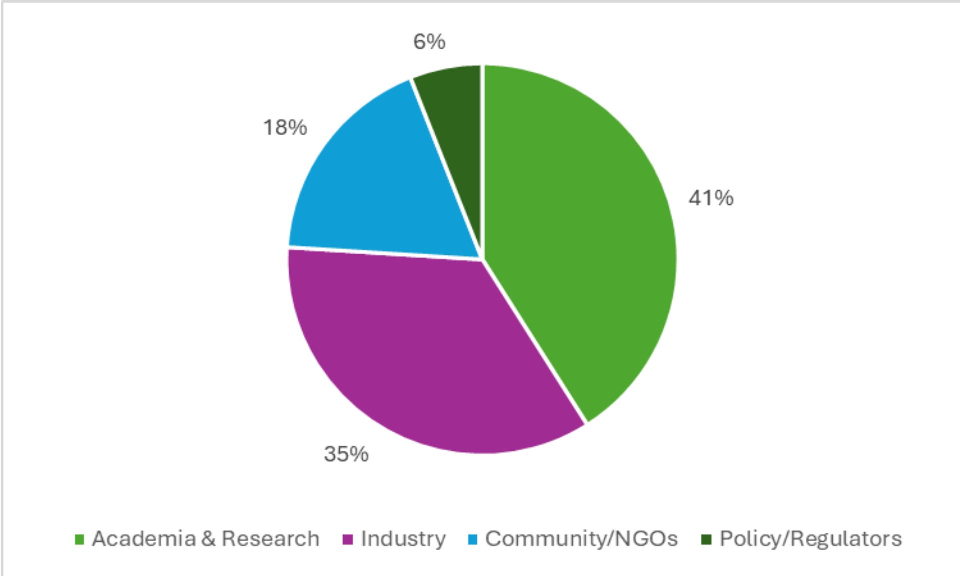

Figure 5: Types of stakeholders participated in a workshop

The workshop employed a structured survey instrument to assess the severity of barriers and the strength of enablers affecting CE transitions in industrial-urban symbiosis. Barriers and enablers were organized into four categories: (1) Institutional and Organizational, (2) Spatial, (3) Socio-economical and Technological, and (4) Regulatory. Within each category, multiple specific factors were presented to participants for evaluation. Participants rated each individual barrier and enabler on a 5-point Likert scale, where 1 = I do not know, 2 = no barrier/enabler, 3 = weak barrier/enabler, 4 = moderate barrier/enabler, and 5 = strong barrier/enabler. For barriers, higher scores indicated greater perceived severity; for enablers, higher scores indicated stronger perceived effectiveness. The mean severity rating was calculated for each individual barrier and enabler across all respondents. Subsequently, category-level mean scores (Table 5) were derived by averaging the individual mean scores of all barriers or enablers within each category.

Our analysis of barriers in the CE transition reveals that regulatory factors remains the greatest obstacle (Table 5). Bureaucracy, characterized by slow approval processes, overlapping authorities and contradictory regulations, received the highest severity rating (4.1 out of 5). Closely following is the challenge of financing (3.8), as many projects face high upfront capital expenditures, scarce external support and reliance on expensive technologies. Equally pressing are biases embedded in current regulation policies (3.8), which continue to favour a linear-economy model and lack meaningful carbon-penalization mechanisms, and spatial policies (3.6) that differ significantly by zoning and regional codes. Profitability conflicts (3.6), notably, the tension between environmental objectives and economic returns, together with the substantial cost of retrofitting existing facilities, completed the list of top five barriers.

Table 5: Workshop-Derived Mean Scores for Enablers and Barriers

Category	Enablers	Barriers
Regulatory (policies & bureaucracy)	4.40	3.6
Socio-economic & Technological	3.85	3.55
Institutional & Organizational	3.80	3.40
Spatial	3.47	3.35

Although gaps in data and information (3.5) and persistent issues around collaboration and trust (3.5) also impede stakeholder engagement, they are slightly less severe than the regulatory and financial hurdles. In contrast, lack of incentivizing policies (2.9), transportation and logistics distances (3.1), and planning uncertainty (3.2) emerged as the weakest barriers, indicating that physical proximity and baseline planning challenges rank below policy and funding constraints. This suggests that investments in

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digital “matchmaking” platforms to connect waste-stream generators with processors could yield faster gains than constructing co-located hubs.

To address these barriers for easier stakeholder engagement, it could be recommended to target both policy and finance, supported by enhanced data sharing and trust-building activities. First, policy reform should focus on mapping overlapping authorities and advocating for unified guidelines that could accelerate approvals. At the same time, financial schemes, such as grants, concessional loans and waste-treatment subsidies, should be designed to lower entry costs and attract private investment. Parallel efforts to launch online communication platforms for waste tracking and potential IS connections could close data gaps and improve trust between the partners.

Regulatory tools earned the highest confirmation (4.5 out of 5) as the most powerful enablers of a CE transition. Next enabler includes incentivizing policies, which could be described in terms of tax breaks and interest-free loans, etc, scoring a 4.3. Equally influential is the geographic clustering of symbiotic industries (4.0), where proximity lowers logistical costs and develops knowledge spill-overs. High levels of technological readiness, including digital twins, real-time IoT monitoring and integrated platforms, also play a vital role (3.9), while growing social responsibility and rising consumer demand for environmentally friendly products lend further momentum (3.8). In contrast, institutional mechanics provide less effect. Dedicated coordination and facilitation roles achieved a solid but lower rating of 3.7, and investments in expertise development, through training programs and pooled resources, received a middle 3.5. The lowest rating was received by business-model alignment (3.2), suggesting that companies still struggle to align CE principles with existing revenue structures.

In mapping the strongest barriers to their enablers, a clear pattern emerges: policy reform and financial incentives are in the corner stone of CE transition. For regulation, the average severity rating for contradictory and overly bureaucratic rules (3.8–4.1) is resonated by the strength of calls for clear technical guidelines and robust incentives (4.3–4.5). Similarly, for financing, while high capital expenditures (3.8) remain major hurdles, stakeholders uniformly support interest-free loans, tax breaks and other supporting mechanisms (4.3). Spatial, informational, and organizational factors pose challenges but also offer opportunities. Zoning limits and long distances can slow progress, but placing eco-industrial parks in regions with strong infrastructure and related industries can reduce costs and boost collaboration. A lack of data sharing and trust can hinder engagement, yet digital tools like open data platforms and real-time monitoring help improve transparency and match waste streams more effectively. Likewise, limited planning capacity can be addressed through dedicated coordinators, training programs, and partnerships between academia and industry to support small businesses and improve implementation.

These findings lead into suggestion of four strategic priorities. First, it is recommended to codify and incentivise by developing a unified regulatory standard system for IS and waste circularity, alongside rolling out tax credits, low-interest financing or subsidy schemes tailored to pilot projects. Next, building digital and physical platforms, launching an open-access data portal or digital twin network for waste-stream matching and zoning eco-industrial clusters, will create the connection between producers, processors and end users. Third, strengthening coordination and skills through the appointment of neutral facilitators and investment in joint training initiatives will bridge organizational gaps. Respondents point clearly toward policy reform and targeted incentives as the highest-order priorities, with strategic clustering and digital collaboration tools amplifying their impact, and organisational enablers knitting the entire ecosystem together.

3.4 Broad-ranging (cross-hub) indicators, derived from DBE Analysis

Finally, all these drivers, barriers, and enablers were grouped into a set of factors, which were then subcategorised into indicators (Tleuken et al., 2025a). These indicators are still very broad and not yet aligned with the specific scope of our work. They represent an initial step in the development process. The next stage involves scoping these indicators according to two non-technological themes: the societal dimension and regional development. The final step applies the niche perspective of the MLP, which refines the selection and results in a list of indicators. These selected indicators then require operationalization for practical application and need to be checked back with the hubs for further selection.

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Table 6: Broad-ranging indicators, derived from DBE Analysis

Factor	*Subfactor*	*Indicator*
Social integration	Aligning Stakeholder Values with CE Principles	Consumer perception
		Environmental impact
		Social responsibility
		Economic impact
	Building Inter-Stakeholder Trust	Confidentiality
		Trust building
		Security
	Addressing Critical Social Factors	Social inclusion
		Participation equality
		Affordable housing
	Optimizing Stakeholder Coordination	Organizational management
		Stakeholder management
		Sustainability & Environmental interests management
	Enhancing Stakeholder Communication	Communication among stakeholders
		Communication about environmental effect
	Ensuring Collaborative Engagement	Diverse stakeholder engagement (including the gender dimension)
		Intersectoral collaboration
		Shared benefits
		Innovative tools usage for enhanced collaboration
	Enhancing Stakeholder Awareness	Education
		Motivation and Attitude
		Commitment
	Exhibiting Leadership Commitment to CE	Leadership and Commitment
		Alignment of Objectives
	Ensuring Access to Quality Information	Accessibility & utilization
		Data quality
		Information sharing
		Information usage
	Developing Specialised Expertise	Training and education
		Strength of resource pool knowledge
Operational efficiency and risk management	Managing Operational Uncertainty	Risk management
		Stakeholder dependency
		Network stability
		Process continuity
	Optimizing Transportation Logistics	Geographical proximity
		Traffic and Accidents
		Logistics sharing
	Ensuring Profitability in CE Practices	Environmental economic impact
		Economic benefits
		Operational efficiency
		Community development
	Conducting Strategic Planning	Planning and Preparation Efficiency
		Infrastructure and Resource Management

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		Sustainable design
	Aligning Business Model with CE	CE Practices implementation
		Innovation & business model evolution
		Customer service
		Flexible Solutions for Sustainability
Technological development and integration	Ensuring Technological readiness	Software Development and Usability
		Integration and Collaboration Platforms
		Operational Efficiency and Optimization
		Risk Management and Value Chain Optimization
	Achieving Systemic Integration	System thinking
		Data Integration and Predictive Models
		Technology integration
		Technology integration
		Collaboration mechanism
	Promoting Autonomous Operations	Diversification of technological solutions
		Diversification of geographical locations
		Complementarity of stakeholders
	Facilitating Adaptation to change	Technology Adaptation and Upgrade
		Community integration
		Innovation
		Unlearning capability
		Community acceptance
Resource and environmental management	Ensuring Resource Accessibility	Internal resources
		Capacity building
		Environmental resources
	Facilitating Symbiotic Resource Exchange	Resource reliability
		Operational quality
		Technological sustainability
		Waste exchange feasibility
		Supply chain development
	Facilitating Materials Reuse Market Development	Market access
		Market stability
		Product strategy
		Consumer perception
Policy and governance	Formulating Strategic Policy Frameworks	Strategic frameworks
		Educational and Professional Development
		Urban and Economic Development
		CE and Environmental Integration
	Implementing Standardized Practices	Quality assurance
		Terminology and Definitions
	Enforcing Regulatory Compliance	Compliance
		Waste management
		Policy enforcement
	Strengthening Regulatory and Governance Frameworks	Institutional support
		Governance organizational capacity

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	Aligning Public-Private Sector Interests	Integration of Public and Private Systems
		Ownership
	Reducing Bureaucratic Processes	Procedural efficiency
		Simplicity of procurement and reporting
	Implementing Incentive-based Policies	Policy frameworks & incentives
		Enterprise sustainability incentives
		Financial mechanisms & taxation
Research and Innovation	Advancing Research and Innovation	Technological advancements
		Research & development collaboration
	Evaluating Effectiveness	Monitoring and Evaluation Tools
		Indicators for Sustainability and Industrial Synergy
		Quantitative assessment
Financial and economic viability	Securing Sustainable Financing	Access to Funding
		Investment
	Assessing Project Feasibility	Infrastructure efficiency
		Collaborative partnerships
		Resource optimization
		Economic feasibility
		Heterogeneous connectivity
	Creating Employment Opportunities	Job retention
		Job creation

3.5 Indicators for *stakeholder engagement* and *regional development* in the non-technological topics context

This subsection turns indicators that emerged from the DBE analysis into two selected, coherent topics, namely *stakeholder engagement* indicators and *regional impact* indicators, as it is mentioned in the Grant Agreement. This subsection explains how the indicators were filtered, grouped and assigned to the two non-technological topics that matter most for H4C stakeholder engagement. These metrics are now published as supplementary material of Tleuken et al. (2025a).

The filtering and allocation of indicators followed a structured method to ensure conceptual clarity. Each indicator was assessed for conceptual fit by comparing it against the topic definitions established in D3.2. Indicators were allocated to one of two non-technological topics: the societal dimension, which includes themes such as inclusion, trust, acceptance, behavioural change, and community benefits, and the regional development and (inter-)organisational collaboration dimension, which covers economic vibrancy, employment, infrastructure, governance.

Table 7: Indicators for non-technological topics, selection of "societal dimension" and "regional development"

Societal dimension	**Regional development & (inter-)organisational collaboration**
Consumer perception	Economic impact
Social responsibility	Environmental-economic impact
Social inclusion	Economic benefits
Participation equality	Job creation
Community acceptance	Job retention
Community development	Market access
Community integration	Market stability

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Societal dimension	**Regional development & (inter-)organisational collaboration**
Trust building	Supply-chain development
Diverse stakeholder engagement (including the gender dimension)	Logistics sharing
Inter-sectoral collaboration (civic–industry)	Infrastructure & resource management
Shared benefits (fair value distribution)	Infrastructure efficiency
Communication among stakeholders	Geographical proximity
Communication on environmental effects	Network stability
Education (general public)	Process continuity
Motivation & attitude	Operational efficiency
Commitment (citizens, NGOs)	Operational quality
Leadership & local champions	Innovation & business-model evolution
Accessibility & utilisation of hub facilities	Technology integration (shared assets)
Affordable housing (gentrification risk)	Integration & collaboration platforms
Security & confidentiality of personal data	Data quality / information sharing
Sustainability & environmental-interest management	Data integration & predictive models
	Planning & preparation efficiency
	Governance & organisational capacity
	Policy frameworks & incentives
	Access to funding / investment
	Risk management (network-level)

3.6 Embedding the context-specific indicators into the MLP perspective

The transition literature identifies three layers that co-evolve during systemic change, as outlined by Geels (2002). At the innermost level are niches, the environments such as LL where new socio-technical configurations can be tested and refined. Surrounding this is the regime layer, which comprises the dominant structures, rules, and infrastructures that provide stability to a regional system. At the broadest level lies the landscape, made up of slow-moving political, economic, and cultural trends that shape the context in which change occurs. Mapping our stakeholder engagement indicators onto these layers helps clarify where signs of progress are likely to emerge first, how innovations must scale to influence mainstream systems, and which external forces might affect the H4C development.

The mapping of indicators followed a logic based in three key considerations. First, we identified the primary area of change by deciding where each indicator is most likely to emerge and be influenced initially. For niche layer the primary area is proposed to be the LL, for the regime level – the regional system area, whereas for the landscape level – a macro context area is proposed. This helped determine whether the indicators belongs primarily to the niche, regime, or landscape layer.

Niche-level indicators represent innovation-driven, localized activities primarily concerned with developing new practices and enhancing stakeholder engagement, experimentation, and societal acceptance. Indicators such as community acceptance, trust building, diverse stakeholder engagement, inter-sectoral collaboration, technology integration, and innovation & business-model evolution exemplify niche-level experimentation and co-creation processes could be further tested within LL. Regime-level indicators continue to represent established infrastructures, institutions, regulatory frameworks, and systemic operational practices that maintain stability but potentially hinder rapid transformative change. Indicators such as governance and organizational capacity, infrastructure efficiency, market access, and policy frameworks & incentives typify regime-level dynamics. Lastly, landscape-level indicators reflect broader contextual or macro-level influences, including economic stability, overarching

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sustainability trends, and societal demands that exceed the direct control of individual initiatives, influencing regime and niche activities indirectly.

Table 8: MLP perspective on list of potential indicators
*(Indicators marked in **bold** are selected for further treatment.)*

	Niche	Regime	Landscape
Societal dimension	· Community integration · Consumer perception · Social responsibility ***· Community acceptance*** · Participation equality ***· Diverse stakeholder engagement (including the gender dimension)*** · Trust building · Inter-sectoral collaboration · Shared benefits · Communication among stakeholders · Communication on environmental effects · Education · Motivation & attitude · Commitment (citizens/NGOs) · Leadership & local champions ***· Accessibility*** & utilisation of hub facilities	· Community development · Sustainability & environmental interest management · Security & confidentiality of personal data · Affordable housing	
Regional development & (inter-)organisational collaboration	· Logistics sharing · Geographical proximity · Process continuity · Integration & collaboration platforms · Data quality / information sharing · Data integration & predictive models ***· Innovation & business-model evolution*** · Risk management (network-level) ***· Job creation*** · Job retention	· Economic impact · Environmental-economic impact (regional) · Economic benefits · Market access · Market stability · Supply-chain development · Infrastructure & resource management · Infrastructure efficiency · Network stability · Operational efficiency · Operational quality · Planning & preparation efficiency · Governance & organisational capacity · Policy frameworks & incentives · Access to funding / investment	· Environmental-economic impact (national/EU) · Macro-level market stability

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3.7 Criteria for selecting potential **context-specific indicators**

We have developed a way to guide the selection of meaningful, potential indicators for assessing non-technological key challenges. From the different topics/themes we came up with in Deliverable D3.2 (see also Figure 2) *stakeholder engagement* and *regional development in H4C* were chosen, according to the Grant Agreement, as topics to focus.

We aim to suggest indicators for tracking and evaluating the non-technological dynamics of the transition processes taking place in H4C, but cannot focus on all three levels of the MLP. In our project we focus on the niche level where new innovations emerge, but keep the regime level with established practices and rules (such as market and investment barriers), and the landscape level (broader trends influencing the system such as regulations) out of discussion.

We start suggesting indicators that we base on our analyses of DBE (see Tleuken et al., 2025a) and non-technological challenges (Deliverable D3.2). We then select indicators that we see belong to the niche level of the MLP and make a selection of indicators feasible and relevant to our project. In the course of the project we then agree with the different hubs which ones are actually relevant for them. Only these ones will then be analysed further throughout the project.

In order to derive at the list of indicators from DBE analysis and non-technological challenges we carry out the following steps:

Step 1: Derivation of potential candidate indicators

Step 1a: Our starting point was the identification of DBE (Table 6) related to *the societal dimension* and *regional development* (Table 7) based on literature (Tleuken et al., 2025a). These factors were then mapped onto the MLP framework (Table 8), distinguishing between developments at the niche, regime, and landscape levels. From this mapping, we derived a preliminary set of potential candidate indicators – particularly focusing on niche-level indicators. In the LL we will check with the hubs whether these are relevant for capturing the dynamic interactions and learning processes.

Step 1b: Checking these potential candidate indicators back with the key challenges mentioned in the interviews in Deliverable D3.2 From the key challenges (see Table 9 for an overview, see Deliverable D3.2 for details) we derived the relevant key performance indicator candidates for our H4C linked to the both dimensions selected. We compare the challenges named in Deliverable D3.2 (focusing on the rows related to stakeholder engagement and regional impact, i.e. for instance *societal and community relations*) to the potential preselected indicators (stemming from the DBE analysis) to come up with a final list of potential indicators. Some challenges related more to the regime or the landscape level and are therefore not taken into consideration. With this first small selection of indicators we want to make sure that it is feasible, relevant and realistic to track the indicators over the project duration.

Step 2: Categorization using a two-dimensional matrix

To facilitate a context-sensitive selection of indicators (that can later be refined by the LL), we introduced a two-dimensional matrix. This matrix helps us assess and prioritize indicators based on two key criteria:

Feasibility/influenceability through LL: This axis ranges from low to high and captures the extent to which a given indicator is practically feasible to measure (e.g., data availability) and within the sphere of influence of the LL.

Relevance/stakeholder interest: This axis also ranges from low to high and reflects the perceived value of the indicator to local and regional stakeholders. It considers the alignment of the indicator with stakeholder needs and concerns (from the DBE analysis and the challenges mentioned in Deliverable D3.2), its possibility for supporting decision-making and monitoring progress, and its potential to foster engagement among actors in the hub.

Each candidate indicator is mapped onto this matrix. This allows us to visually and conceptually identify which indicators fall into the high-feasibility, high-relevance quadrant (upper right quadrant) – making them strong candidates for inclusion in the final monitoring.

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Step 3: Selection of priority indicators

Indicators positioned in the top-right quadrant of the matrix (high feasibility, high relevance) are prioritised for further development, if agreed by hubs to be meaningful. These indicators are expected to offer both actionable insights and stakeholder validity. In contrast, indicators that are either hard to measure or of limited stakeholder interest may be deprioritised, unless they serve a critical strategic purpose or can be made more practical through iterative testing in the Living Labs.

The matrix in Figure 5 categorizes the niche-level indicators from both the *societal dimension* and *regional development dimension*, based on two criteria: **feasibility** (x-axis) and **relevance** (y-axis). Feasibility refers to the ease or practicality of measuring or obtaining reliable data on these indicators through LL activities, including availability of appropriate methods, data sources, and evaluation tools. Relevance for stakeholders refers to how significantly these indicators matter or influence stakeholders' decisions, attitudes, or engagement within LL. Indicators are mapped into four quadrants reflecting combinations of low/high feasibility and low/high stakeholder relevance (Figure 6), assisting in prioritising activities, resource allocation, and strategic focus during niche-level experimentation in LL in H4C.

In the *"High feasibility & High relevance"* quadrant, indicators (e.g., job creation) are both crucial for stakeholders and we assume also practically measurable in the course of the project and/or within the LL. These should be, next to the general indicators (see Section 3.1), prioritised as most important context-sensitive indicators for evaluation, discussed with hubs and taken into consideration during LL.

Low Feasibility, High Relevance Trust building; Motivation & Attitude; Diverse stakeholder engagement; Communication among stakeholders; Supply-chain development; Consumer perception; Job retention; Integration & collaboration platforms; Data quality/information sharing	**High Feasibility, High Relevance** *Stakeholder engagement: (Community) Acceptance*; *Job creation*; *Business models* *Regional impact: Indicators related to I/O models, Infrastructure*
Low Feasibility, Low Relevance Affordable housing; Participation equality; Education; Social responsibility	**High Feasibility, Low Relevance** Commitment (citizens, NGOs); Leadership & local champions; Risk management; Operational quality

Figure 6: Matrix to map niche indicators (x-axis: feasibility, y-axis: relevance)
(Focus is put on the upper right quadrant in green; indicators in grey quadrants are not focus of this project.)

3.8 Operationalisation of selected context-sensitive **indicators**

In this deliverable, we focus on selected cross-hub indicators that are further discussed through our LL activities in our project. For every indicator we indicate whether it contributes to the overall objective of *stakeholder engagement* and/or *regional impact*.

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As a next step we need to operationalize each of the selected indicators in terms of (1) *what* we want to measure (conceptual definition), (2) *how* we want to measure it (operationalization), and (3) how it relates to niche-level "windows of opportunity" in the MLP to support H4C.

Stakeholder engagement:

Additional to the general indicators for stakeholder engagement mentioned in Section 3.1, we came up with indicators derived from literature (based on the DBE analysis, explained in detail in Tleuken et al., 2025a), and summarized in this deliverable in Section 3.2) and cross-checked them with the non-technological key challenges of hubs (summary in Table 9, details in Deliverable D3.2). Furthermore, we integrated the gender dimension to ensure diversity.

Table 9: Summary of non-technological key challenges per hub

	German Hub	Dutch Hub	Basque Hub	Turkish Hub
Societal and community relations	Societal impact of Sustainable Aviation Fuel (SAF)	Concerns over the safety of emerging technologies	Social resistance against waste facilities, renewable energy installations, CO_2 storage	Acceptance and skilled labour as key challenges
Regulatory uncertainties	Regulation as uncertain driver for demand of Sustainable Aviation Fuel (SAF)	Lack of clear policies on hydrogen production, storage, and distribution	Long permitting processes, uncertain changes of legislation	Frequently changing, complicated
Economic challenges	Market and investment barriers	Limited financial incentives or subsidies	High capital need and operational expenditures, need for business cases of IS	Market and investment barriers
Infrastructure	Infrastructure for hydrogen and renewable energies	Integrating hydrogen, electricity, and gas networks	Needed for H_2 & CO_2 transport, upgrade of electrical grid	
Organisational and collaborative capacities		Misaligned stakeholder priorities, lack of specialized workforce		

- **(Community) acceptance:** This indicator is jointly derived from the analysis of DBE (Tleuken et al., 2025a) and the non-technological key challenges of hubs mentioned in the interviews we conducted for Deliverable D3.2. This indicator belongs to the societal dimension of the non-technological issues that are relevant to IS and H4C (see Table 2), can therefore contribute to measuring the ***value for stakeholders*** and with that the overall ***stakeholder engagement***.

  Community acceptance captures the local population’s support/acceptance for or resistance to CE initiatives, including their willingness to engage or adjust to changes. This can be discussed with different types of stakeholders (see Figure 1), potentially using a simple survey asking stakeholders how satisfied they are at the current state with H4C and what is needed to get acceptance. By means of stakeholder dialogues in the LL we can analyse the feedback. High community acceptance signals a encouraging environment for niche development and strengthens local political backing for LL experimentation.

  Acceptance in our project means acceptance of the emerging technologies (or resistance against for instance facilities, mentioned amongst others by the Basque hub as a challenge) that are developed in the H4C communities, or acceptance/resistance of H4C in general

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(mentioned by the German and Turkish hub as challenges), especially if stakeholders have concerns e.g., over the safety of emerging technologies (mentioned by the Dutch hub as challenge).

- **Job creation:** This is a quantitative indicator, capturing – for example – the number and type of new jobs created as a result of H4C implementation. To track that indicator we will make us of the subcontractor (Circle Economy Foundation). The ability to demonstrate job creation enhances the economic appeal of niche innovations. Job creation potential in our project means access to skilled labour (mentioned, for instance, as a challenge in interviews with the Turkish hub in Deliverable D3.2). Measuring the job creation potential brings ***value for stakeholders*** and with that contributes to the overall measurement of ***stakeholder engagement***.

Additional potential indicators for stakeholder engagement and regional impact (in the first place not intended to be directly measured, but to be further discussed in the LL, if feasible):

- **(Innovation in) Business models:** We are expecting innovation and business model evolution. It is not the direct focus of our work package 3, so we do not plan to measure this ourselves. Our project partner KPMG, leader of work package 5, focuses on addressing business models, so we will try to get insights from their work. In the Basque hub it was mentioned during the interviews (conducted for Deliverable D3.2) that there is a need for business cases of IS.

- **(Accessibility of) Infrastructure:** This is primarily a quantitative indicator, tracking infrastructure availability in hubs. This indicator is part of the *regional development*. We can track how infrastructure is provided for the hub regions, for instance, by tracking the length of hydrogen pipelines for the Dutch hub, to enable further use of hydrogen for heating in the built environment.

3.9 **Hub-specific indicators** for *societal engagement* and *regional impact*

In this section we present some first results focussing solely on the **Dutch hub**. This is done for illustrative purposes, to showcase our methodology and approach. We will proceed similarly for the other hubs in the course of Task T3.3.

We would like to clarify that the indicators presented here are based on the general (see Section 3.1) and context-sensitive ones (Sections 3.1-3.8), but specifically discussed and further elaborated for the Dutch hub. This is intended as an illustrative example to demonstrate our approach. We will take a similar approach with the other hubs, depending on their specificities.

The stakeholder ecosystem supporting the Dutch hub is organized into three tiers based on their involvement and contribution to the IS2H4C project, each reflecting a distinct level of influence and type of engagement. The stakeholder analysis and interviews are presented in detail in Deliverable D3.2.

At Tier 1 level of the Dutch hub, national-level authorities are responsible for regulatory approval, policy alignment, safety standards, environmental permitting, and certification of hydrogen technologies. Tier 1 stakeholders are engaged through collaborative involvement, focusing on local permitting, implementation, and operations. Tier 2 involves local actors crucial for implementation, including municipal authorities, community organizations, infrastructure developers, safety assessors, and water management bodies. Tier 3 comprises knowledge and research institutions that support the project through scientific research, innovation, and education. While Tiers 1 and 2 are actively engaged in decision-making and operations, Tier 3 stakeholders primarily need to be kept informed through clear updates on key project milestones, fostering transparency and encouraging feedback. This tiered structure ensures that the Dutch hub is supported by a well-coordinated network spanning various types of stakeholders from industry, regulation, and community.

For the Dutch hub, we could identify **20 key stakeholders** (**Indicator: *Key stakeholders in the Dutch hub***) that are used for further analysis. Apart from categorizing them into tiers, the stakeholders are

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also divided by the stakeholder categories of society, academia, industry, and policy (see stakeholder typology from D3.1 or Figure 1). For the Dutch hub, this overview of allocating stakeholders to the four main groups means:

Policy: NL-P-1, NL-P-2, NL-P-3, NL-P-4, NL-P-5

Industry: NL-I-1, NL-I-2, NL-I-3, NL-I-4, NL-I-5, NL-I-6, NL-I-7

Academia & Research: NL-A-1, NL-A-2, NL-A-3, NL-A-4

Society: NL-S-1, NL-S-2, NL-S-3, NL-S-4

When plotting this into an overview (Figure 7) we see that for the Dutch hub, a diverse range of stakeholders (**Indicator: *Diverse categories of stakeholders in the Dutch hub***) can be considered. The categories are well-spread amongst policy (five stakeholders), industry (seven stakeholders), society (five stakeholders), and academia (four stakeholders).

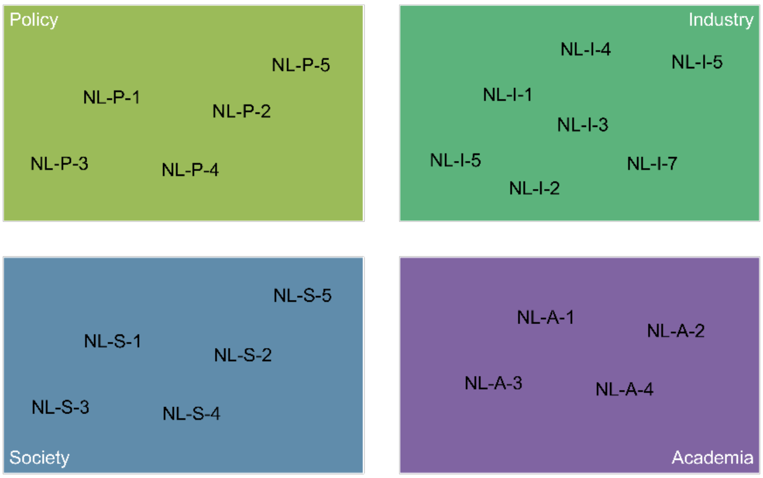

Figure 7: Distribution of stakeholders in the Dutch hub

For comparison with a different hub from the project, we take the Basque hub as distinct counterpart example (see Figure 8): There, the distribution of stakeholders looks completely different compared to the Dutch hub. There, we see, for instance, an underrepresentation of citizens (category society: only one stakeholder) and a lot of stakeholders belonging to the industry category.

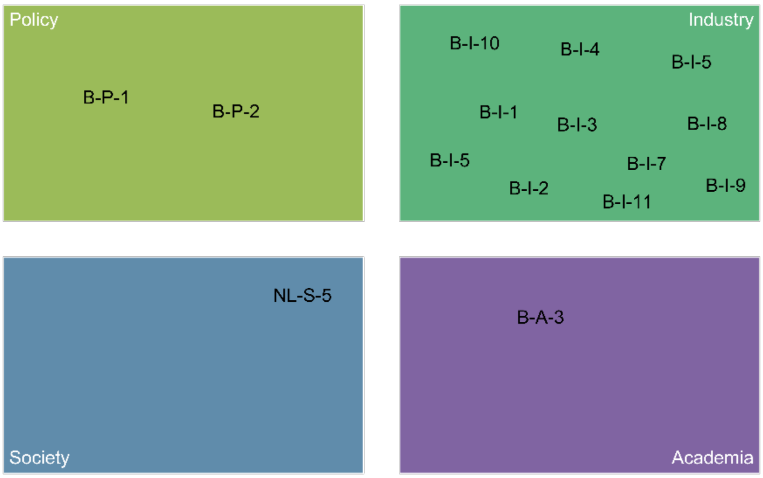

Figure 8: Distribution of stakeholders in the Basque hub

Coming back to the Dutch hub, the stakeholders there can also be organised in ‘circles’ (see Figure 9). The inner circle is presenting the stakeholders who are already on board of the project and part of the

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Dutch hub, the second (middle) circle presents stakeholders that the hub is already in touch with (known stakeholders). The third (outer) circle represent stakeholders they are not yet in touch with.

This categorisation of stakeholders contribute to the **Indicator: *Number of stakeholders in the Dutch hub***. For the Dutch hub, this number would for be **20 stakeholders**. For the Dutch hub, we can further – more specifically – analyse how many stakeholders are already on board (inner circle), will get on board (middle circle), and how many stakeholders are not yet involved, but they plan to get from the third (outer) circle to a more inner circle. This contributes as *indicator for stakeholder engagement*, more precisely for the Dutch hub.

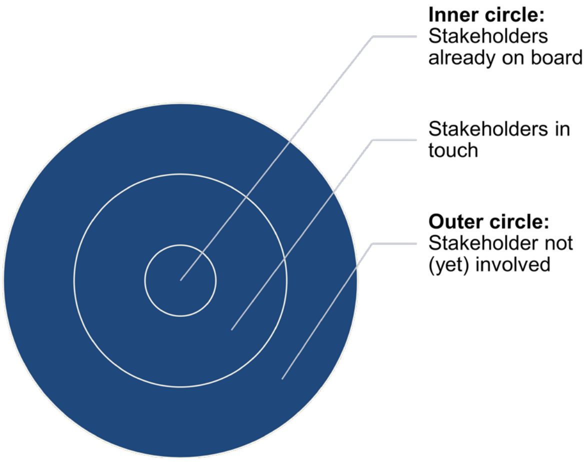

Figure 9: Stakeholders of the Dutch hub organised in circles

In the Dutch Hub, stakeholder engagement is structured according to the MLP, distinguishing between niche, regime, and landscape levels to support an inclusive transition towards a circular economy. At the niche level, innovators and early adopters are leading the way. Approximately twenty process industry companies based in the Twente and the area of Almelo together with H_2Hub Twente, the University of Twente, and local startups, are actively implementing green hydrogen technologies and circular practices. Engagement at this level is driven by pilot projects (such as hydrogen supply initiatives for residential areas in Aadorp and the local crematoria), the development of innovation hubs for experimentation and knowledge sharing, and capacity-building efforts through training programs on hydrogen and CE principles.

At the *regime level*, established actors and institutions such as the municipalities of Almelo and Aadorp, regional utilities, local industries, and regulatory bodies play a key role. These stakeholders are responsible for maintaining and evolving existing infrastructures and regulations, which can either support or hinder the circular transition. Engagement strategies at this level focus on organizing policy dialogues to align local governance with CE ambitions, collaborating on infrastructure planning to incorporate hydrogen solutions, and advocating for regulatory frameworks that enable green hydrogen integration.

The *landscape level* encompasses broader societal forces, including national government agencies, EU institutions, environmental non-governmental organisations (NGOs), and the general public. These actors shape the overarching context through policy, funding, and societal acceptance. Engagement here involves public awareness campaigns to communicate the benefits of hydrogen and circular solutions, policy advocacy at national and European levels, and dissemination of research findings from Dutch Hub activities to inform policy and societal debates.

To bridge these levels, the Dutch Hub could apply *cross-level strategies* that foster integration and learning. These include establishing transition platforms where actors from all levels can co-develop solutions, creating feedback loops so that lessons from niche-level experimentation inform regime practices and landscape policies, and building networks that connect local, regional, and international

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stakeholders to promote collaboration and knowledge exchange. By embedding these multi-layered engagement strategies into the Living Lab approach, the Dutch Hub enhances its capacity to drive meaningful systems change towards a circular and hydrogen-enabled future.

To strengthen the recognition and dissemination of Almelo Energie's approach within the broader sustainability transition, the MLP framework can serve not only as an analytical tool but also as a strategic mechanism. By linking niche-level experimentation, such as the activities of H_2Hub Twente and Almelo Energie, with regime- and landscape-level dynamics, the Dutch Hub can more explicitly position its work within national and EU-level policy objectives. For instance, the drive for all companies to reduce CO_2 emissions due to EU climate targets and rising emission costs is a pressing regime- and landscape-level development. This systemic pressure creates a "window of opportunity" that Almelo Energie and its partners can leverage to make their local solutions (like hydrogen pilots and IS) more relevant and visible. These dynamics could also form the basis for academic research, such as a bachelor's or master's thesis exploring how regional actors operationalise CO_2 reduction strategies in line with EU frameworks.

Building on this potential, the Dutch Hub may also consider the development of a Local Green Deal as a tangible outcome of the LL activities. This early-stage idea, proposed by Almelo Energie, would bring together measurable indicators for both IS and the built environment within a place-based sustainability strategy. What distinguishes this initiative is its focus on implementation in a non-metropolitan, rural setting, which contrasts with the urban-driven approaches common in European initiatives such as the Intelligent Cities Challenge (ICC). By embedding thematic integration and indicator-based monitoring in a less densely populated area, the Dutch Hub could serve as a pioneering model for adapting and localizing the ambitions of the European Green Deal. In this way, the MLP lens not only supports analysis and engagement, but also guides the strategic upscaling and policy embedding of local innovations.

Indicator: *Job creation (potential) in the Dutch hub*

The development of the Dutch hub presents employment opportunities through workforce transformation and skill development initiatives (see Deliverable 3.2 for details). Within stakeholder NL-S-3, which involves transitioning five residential buildings, community centre, and a small business building in Aadorp from natural gas to hydrogen, network operators emerge as key employment stakeholders. The pilot project's approach of keeping existing staff to acquire specialized hydrogen infrastructure installation and maintenance capabilities demonstrates the hub's potential for job preservation through shifting skills rather than displacement. The initiative of NL-S-4 further amplifies job creation potential by identifying skill transformation needs across multiple sectors. Water treatment services company NL-I-1 will require personnel with hybrid competencies combining electrical engineering, water engineering, process and installation engineering, plus specialized permits and safety expertise. The establishment of 'learning communities' within NL-S-4 creates an innovative employment development mechanism that not only addresses immediate skill gaps but also generates new positions in education, training coordination, and knowledge transfer roles. The hub's energy storage initiatives, incorporating solar installations, small wind turbines, and battery systems, open additional employment pathways in renewable energy sectors. This approach to workforce development positions the Dutch hub as a potential employment generator, creating jobs both in direct hydrogen operations and in training, coordination, research, and cross-sector integration activities.

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4. Conclusion and Outlook

As a summary, Table 10 presents an overview table of the selected indicators (split into stakeholder engagement and regional impact) that we plan to continue working with throughout the upcoming tasks in work package 3. The overall indicator (SoReL) will guide the progress; we use a combined SoReL score as metric that communicates progress from concept to implementation.

Table 10: Summary of selected indicators to continue working with throughout work package 3 (indicators with white background: general cross-hub indicators; indicators with light grey background: details to be discussed with hubs in living labs; indicators with dark grey background: measured via other work packages of the project)

	Indicator (Niche)	What it measures	How it is measured
Stakeholder Engagement	***Societal Readiness Level (SoReL)***	Combined SoReL score as metric that communicates progress from concept to implementation	Level 1 (early awareness of CE) to Level 9 (hub operations are fully embedded in regional practice)
	Number of stakeholders in hubs	Number of stakeholders involved in the hub	# of stakeholders
	Diverse categories of stakeholders (including the gender dimension) in hubs/living labs	Categories of stakeholders in the hub/living labs	# of categories
	Frequency of workshops	How often are workshops conducted with stakeholders?	# of workshops per year
	(Community) acceptance	**Value for stakeholders** Local support and willingness to engage with H4C activities	Simple survey or via stakeholder dialogues amongst participants of the LL, asking about satisfaction level (low – high community acceptance)
	Job creation (potential)	**Value for stakeholders** New employment generated through H4C initiatives	Number of new jobs (measured/tracked by Circle Economy Foundation)
	Business models	Emergence of new circular businesses and practices	(not done by WP3, but WP5)
Regional impact	*Indicators from MRIO*	Socio-economic (e.g., regional impact on job creation) and environmental impact (e.g., regional impact on dioxide carbon emissions) of each H4C region	Using I/O modelling approach
	Infrastructure	Availability of physical infrastructure	Examples: Length (km) of e.g., hydrogen pipelines

4.1 Outlook on Living Labs

As the IS2H4C project progresses, LL are planned to evolve from conceptual frameworks into practical tools for discussion of implementing CE solutions through stakeholder-driven experimentation. Initially developed through a top-down approach, where methods, goals, and success criteria were designed at the project level, the next phase will shift toward bottom-up validation of the socio-economic indicators directly within the LL. Through participatory engagement, local stakeholders will assess how

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relevant and applicable these indicators truly are. The aim is not only to test predefined metrics but also to adjust them based on real-world interactions, challenges, and community insights.

LL will serve as regional exchange and working formats, addressing non-technological challenges such as regulatory barriers, public acceptance, political alignment, and inter-organisational coordination. These activities involve a broad spectrum of local stakeholders from industry and research to civil society and governance ensuring that diverse perspectives are embedded into the solution-building process. Practically, LL initiate social innovation processes, facilitate discussions on technological and non-technological solutions, and trigger stakeholder engagement tailored to regional challenges.

4.2 Outlook on Expert Panels

The expert panels established by KPMG (in Task T3.2.1) serve as a critical bridge between broad non-technological challenges and the regionalised socio-economic analysis. The panels will convene thematic discussions on regulatory, societal, ethical, and green industry topics – tailored to local contexts in regions where project partners are established, bringing together a diverse set of expert voices and stakeholder perspectives. A total of six outputs will derive from these expert panels, contributing in a specific and complementary way to Task T3.3:

1. Identification of non-technological barriers and enablers – baseline for understanding the soft infrastructure (policy gaps, ethical tensions, market dynamics, or societal resistance) that shapes the feasibility and speed of IS2H4C implementation. These findings will contextualise both direct and indirect impacts in the regions hosting the H4C demo hubs.
2. Context-specific socio-economic priorities and concerns – capture the heterogeneity of regional ecosystems, from employment patterns to social readiness and investment gaps. These insights will inform the calibration of regional input-output models, ensuring they reflect real-world differences in stakeholder values, socio-economic structures, and market behaviour.
3. Recommendations on policy and governance scenarios – concrete modelling inputs for Task T3.3's MRIO analysis. This will support the formulation of future-oriented scenarios that include differentiated governance and incentive structures, which are necessary for assessing the long-term sustainability and resilience of regional economies.
4. Stakeholder engagement insights – feeds directly into the construction of the SoReL framework. These qualitative data points (covering expectations, perceived value, trust levels, and willingness to participate) will serve as proxies for stakeholder uptake and behavioural change, enabling the development of nuanced engagement indicators.
5. Feedback on CE implementation strategies – helps to identify both systemic resistance and success factors. This informs not only impact metrics, but also process indicators for implementation and policy transferability.
6. Region-specific knowledge transfer and capacity building needs - ensures that the indirect and induced impacts captured in Task T3.3 (e.g., institutional readiness, skills gaps, training needs) are grounded in actual regional capacities.

Together, these six outputs ensure that the assessment framework is both evidence-based and sensitive to regional diversity, drawing from a wide range of territorial insights – including regions beyond the demo hubs – to capture shared challenges, context-specific dynamics, and transferable lessons.

4.3 Outlook on Multi-Regional Input-Output Modelling

As H4C aim to drive sustainable regional development through industrial, urban, and rural collaboration, engaging municipalities alongside firms and research actors, and through resource efficiency. Thus, it is crucial to understand and measure the value they bring beyond technical performance. The analysis will be based on regional and, if appropriate data is available, MRIO modelling, which allows us to simulate how the implementation of H4C changes flows of materials, energy, and economic activity. By examining both intra-regional exchanges and inter-regional spillover effects, the modelling will help to reveal how these hubs influence broader systems of production and consumption. The task, scheduled to begin in April 2026 under the leadership of the University of Twente with the participation of

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international project partners, will identify key indicators – such as employment levels (using the job-creation methodology developed by the Circle Economy Foundation), carbon emissions, water use, and waste generation will be identified through literature review and stakeholder input, and then quantified using data collected for four pilot regions. Where regional data is limited, national statistics will be adjusted and downscaled to reflect local conditions. The study will compare two scenarios: before and after the implementation of H4C. It will help to estimate the added socio-economic and environmental value. This includes capturing changes in sectoral interdependencies, job creation potential, and reductions in environmental pressures. Each of the four hubs under analysis reflects a distinct regional profile. Ultimately, the indicators generated through this approach provide a structured way to monitor progress and support decision-making, offering practical evidence of the broader benefits that H4C can bring to regions aiming for circular and inclusive growth.

4.4 Social Networks Perspectives in H4C

H4C operate through various networks that integrate different perspectives including resource sharing, communication, monetary flows, and regulation imposing dimensions (Figure 10). At the resource level, actors are interconnected through waste and by-product exchanges, many stakeholders serve simultaneously as both producers and users of physical resources. This dynamic emphasises interdependence and fluid roles within the network. Interestingly, certain external or "miscellaneous" organizations, those not tied directly to a specific hub, play an enabling role by developing resource production technologies, though the resource consumption remains hub-centred and domestically bound.

At the community level, every H4C features engagement from at least one community-based stakeholder. This inclusion reflects the hubs' role in developing urban-rural-industrial linkages, moving beyond traditional industrial clusters to embrace socially embedded circularity. These community actors often act as resource users, anchoring IS practices in local needs and capacities. The monetary level surfaces in the form of shared infrastructure investments, operational cost structures, and revenue mechanisms between organizations. While not explicitly visualized in the network, such exchanges underpin the feasibility and resilience of symbiotic relationships. Cost-sharing, joint project funding, and pooled investments help scale technologies and reduce individual risks. Lastly, the regulatory level frames the entire ecosystem. National and local policies guide approvals, safety standards, and environmental compliance. Though not shown in the resource network figure, regulatory actors indirectly shape flows by enabling or constraining certain exchanges. Their presence is especially critical where innovative technologies and cross-sector collaboration challenge traditional frameworks. Altogether, H4C embody a multilevel configuration where material, social, financial, and institutional elements coalesce to enable circularity within and across regional hubs. This multi-levelled perspective is still under development and will be further refined in upcoming project deliverables, where deeper insights into governance structures, financial flows, and regulatory coordination will be explored.

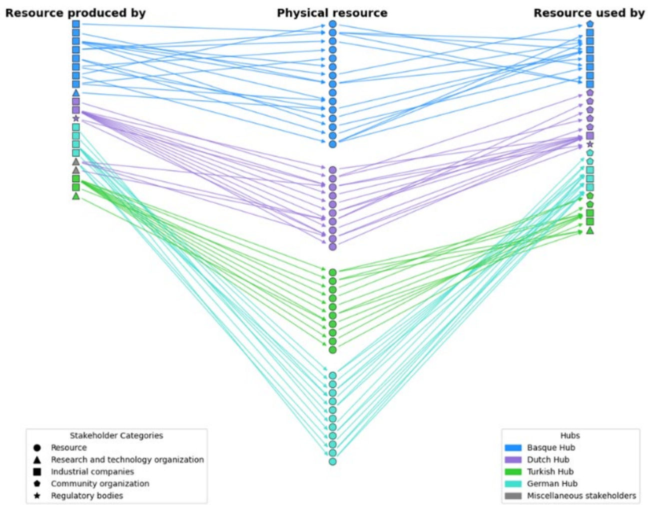

Figure 10: Example of a resource exchange level perspective (based on a working paper by Tleuken et al., 2025b)

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