Vetytalous Etelä-Pohjanmaalla
Hydrogen economy in South Ostrobothnia

VEPE project T2.1 Background mapping of hydrogen ecosystems

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TIIVISTELMÄ/ABSTARCT

This partial report encompasses the results of task T2.1 of the VEPE project. The aim of this task was to perform a benchmarking of existing hydrogen ecosystem literature and based on other publicly available material.

Ecosystems are recently gaining the attention of governmental authorities around the world as a suitable alternative to tackle complex challenges such as the transition towards clean energy technologies. Ecosystems as flexible social structures, enable the development of innovative solutions from the collaborative work of multiple and heterogeneous social actors (Asplund, Björk, Magnusson, & Patrick, 2021). These social structures strengthen and expand by the interactions and interdependencies between actors, resulting in resource sharing, knowledge transfer and co-creation. A key aspect in ecosystems is to improve the creation of bonds of trust and reciprocity between members to facilitate risk sharing and decision making (Kola, Koivukoski, Koponen, & Heino, 2020; Zeng, 2022).

According to the recent literature, ecosystems are characterized by its co-evolution over time (Gifford, McKelvey, & Saemundsson, 2021; Maguire, 2022; Riasanow et al., 2020). Therefore, ecosystems reach several stages from emergence to consolidation. During the ecosystem emergence, there are four key processes taking place: *value discovery, building collective governance, building contextual embedding,* and *acquiring resources* (Thomas, Autio, & Gann, 2022; Thomas & Ritala, 2022). Processes in ecosystem emergence could be successfully approached when there is a strong commitment from its members, including a specific definition of the role of the orchestrator (Autio, 2022). The relevance of the orchestrator' role has been emphasizing in the literature in keeping coherence and alignment between individual interests and the system-level value proposition (Hurmelinna-laukkanen & Nätti, 2018; Parida, Burström, Visnjic, & Wincent, 2019). As the orchestrator has simultaneously a peripheric and granular perspectives of the ecosystem, it is possible to benefit from pooling resources to build an innovative solution adjusted to the market needs (Autio, 2022; Pinilla-De La Cruz, 2024).

In the international landscape, hydrogen ecosystems appear closed related to the concept of hydrogen valleys. Indeed, hydrogen valleys are ecosystems that meet some characteristics in terms of scale, value chain coverage and geographic delimitation (Weichenhain, Kaufmann, Hölscher, & Scheiner, 2022). Currently, there are relevant initiatives in several countries in Europe, as well as in Asia, Australia, and America. Finland also takes part of hydrogen valleys as the BalticSeaH2 and the BotH2nia Valley. Experiences from hydrogen valleys around the world provide valuable insights for the further emergence and development of regional clean hydrogen ecosystems in Finland.

At the national level, collaboration networks as the H2 Cluster Finland, BotH_2nia and Hydrogen research forum are supporting the regional and local initiatives in terms of clean hydrogen. As a result, the current Finnish hydrogen portfolio shows tangible actions on the country's commitment to the development of the hydrogen economy and collaborative networks.

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1 Conceptual background of ecosystem emergence

1.1 Scope of the analysis

This partial report has been prepared as part of the VEPE project, task T2.1 in work package 2. The project has been financed by the European Regional Development Fund (ERDF), Regional Council of South Ostrobothnia, University of Vaasa, and Seinäjoki University of Applied Sciences. The aim of this activity was to perform benchmarking of existing hydrogen ecosystem literature and based on other publicly available material. As these results will be used on the forthcoming activities of the VEPE project, some specific hydrogen initiatives have been as a reference for building a clean hydrogen ecosystem in South Ostrobothnia.

For this background study, data was collected from publicly available sources such as peer-reviewed scientific articles, international, national public reports, and projects websites.

1.2 Definition of ecosystems in the context of sustainability

Ecosystems are becoming increasingly relevant in sustainability agendas and public policies for the energy transition. One of the main reasons is due to the role of new social structures such as ecosystems in the development and scaling of technological and business innovations. As approached in studies on socio-technical transitions conducted by Geels (2012) and Geels et al. (2019), at the niche level, ecosystems function as structures that, by expanding and strengthening, drive the transformations towards cleaner energy systems. By acting as ‘carriers’ of change, ecosystems are mutable and adaptive. Therefore, the concept of ecosystem can capture the diverse nature of the initiatives required to respond to contemporary phenomena such as climate change (Paasi, Wiman, Apilo, & Valkokari, 2023).

Notably, denoting ecosystems as social structures originates from biological systems composed by living organisms in a particular environment that is now applied to meta-organizations (Tsujimoto, Kajikawa, Tomita, & Matsumoto, 2018). As in nature, ecosystem members interact creating interdependencies and co-evolving at the individual and group level. Ecosystems have their *raison d'être* in the mutual creation of value that emerges from collaboration and the exchange of resources (Jacobides, 2018; Linde, Sjödin, Parida, & Wincent, 2021; Valkokari, Hyytinen, Kutinlahti, & Mari, 2021).

Although ecosystems can emerge organically or deliberately around a focal entity or 'key stone', usually these structures in formation require specific efforts both in the architecture of the ecosystem, as well as in its processes of developing its value proposition (Thomas et al., 2022). Particularly in socio-technical fields, such as the advent of the hydrogen economy, intense collaborative efforts of public and private actors are required to bring innovations to commercial levels and achieve further social adoptions (Pinilla-De La Cruz, 2024).

In order to provide an ecosystem concept to assist in the further proposal of a clean hydrogen ecosystem in South Ostrobothnia, the study by Tsujimoto et al. (2018) has been selected as a conceptual basis, where ecosystems are defined as *"a historically self-organized or managerially designed multi-layered social network consists of actors who have different attributes, decision principles and beliefs to provide a product or service system"* (Tsujimoto et al., 2018, p. 55). According to the mentioned study, some constituent elements of ecosystems are:

- Delimitation within a specific scope of action, for example, in terms of the need to be addressed and the range of solutions to be developed.
- Ecosystem members are related to the activities included within the ecosystem’s scope, such as actors from the value chain *per se* and those who support from strategic management side, policy makers, research and development institutions, financiers, etc.
- Actors build a wide spectrum of relationships with ecosystem members through visible or invisible flows, including strong relational bonds of trust and reciprocity.
- Ecosystems develop and consolidate over time.
- Ecosystems enclose multiple layers.

- Relational bonds between ecosystem actors have attributes that include underlying variables derived from the convergence of their beliefs, principles, and culture.
- A key concept in ecosystems is the coherence between the intentions and actions of individual actors in relation to the value proposition at the system level. In such a way, coherence is achieved in the ecosystem from a certain congruence between the rationales of actors in decision-making and their expectations with the ecosystem.

Thus, the success of an ecosystem would be a combination of natural, structural, organizational, and cultural factors that collectively drive sustainability and ecosystem performance (Grobbelaar, 2005; Pinilla-De La Cruz & Rabetino, 2024).

1.3 Types of ecosystems

Ecosystems in the literature are classified according to their outcomes into three types: innovation ecosystems, business ecosystems and knowledge ecosystems (Kola, Koivukoski, Koponen, &; Heino, 2020; K. Valkokari, 2015). This distinction is important to recognize the orientation that an ecosystem has or would have in terms of its value proposition. Although in some cases, ecosystems converge in more than one category due to the intersection of common elements, for example, in the development of innovation with business expectations, etc.

1.3.1 Innovation ecosystems

An innovation ecosystem could be defined as a dynamic network of relationships fostering the co-creation of value through the exchange of information and financial resources (Valkokari et al., 2021). Innovation is developed through networks at the human and business levels, impacting the technological, economic, social, political, and environmental dimensions (Adner, 2017; Sjödin, Parida, & Visnjic, 2022; Still, Huhtamäki, Russell, & Rubens, 2014).

Furthermore, innovation ecosystems would bridge the exploration of new knowledge with its practical application, enabling the co-creation of value within business ecosystems (Valkokari, 2015). Innovation ecosystems include companies intensively in technological development, research institutes, policymakers, integrating companies, local intermediaries, innovation agents, and financial networks providing funding (Valkokari, 2015). Innovation ecosystems are characterized by being delimited in a specific geographical space, where their actors interact at distinct levels of openness and collaboration. As innovations are nowadays a pillar of sustainability, clean energy-oriented innovations are increasingly driven by collaboration between cross-sectoral actors, including companies, public organizations, academia, users, and even non-profit organizations (Adner, 2017; Oskam, Bossink, & de Man, 2021; Valkokari et al., 2021).

1.3.2 Business ecosystems

According to Valkokari (2015), business ecosystems are characterized by a focus on creating and capturing value for potential users and for member organizations. Usually, business ecosystems members are companies and organizations of different nature sharing resources, assets, and knowledge to create value for the customer. Mostly, this type of ecosystem is linked to a shared platform coordinating its operation, hence, technological applications for the interaction of ecosystem members are crucial here. Business ecosystems can also operate around a focal company as a traditional configuration. Given the priority of delivering customer value, these types of ecosystems locate the key actors of the value chain in the first level of interaction and attention (Moore, 1993; Valkokari, 2015).

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1.3.3 Knowledge ecosystems

The aim of knowledge ecosystems is the exploration of new knowledge (Valkokari, 2015). Therefore, the exchange of knowledge becomes the main activity in this type of ecosystem, and the expected outcome would be the generation of new and useful information. The relevance of these ecosystems lies in the creation of critical mass on new topics that require specific attention, as well as the support of new industries, new technological applications so that they have room for discussion and validation. Members of knowledge ecosystems can arise from multiple shores, e.g., universities, research institutes, industrial actors of great relevance in the context, technology companies, integrating companies, regional, local, or national public authorities, etc. (Valkokari, 2015).

1.4 Processes through the ecosystem emergence

The process of emergence of ecosystems can originate from different edges. Some ecosystems arise as initiatives of one or more companies to create an ecosystem architecture according to their own vision and proceed to convene actors in different segments of the value chain. On the other hand, other ecosystems can be initiated as a response to the need for action at the regional or local levels to overcome complex challenges, getting involved to multiple public and private actors in these endeavors. Overall, the process of ecosystem emergence requires efforts in aligning actors to discover their individual value in the ecosystem and collectively create a system-level value proposition (Thomas et al., 2022). Particularly, in the initial stages of self-organized public-private ecosystems, the roles of the actors may not be entirely clear from the beginning and may vary over time (Asplund et al., 2021; Pinilla-De La Cruz, 2024). Additionally, it is necessary to get consensus among members regarding the one who would exercise the role of orchestrator.

According to Thomas et al. (2022), there are four critical processes during the ecosystem emergence as *value discovery, collective governance, acquiring resources and contextual embedding* (Figure 1). Each process represents a specific layer of the ecosystem:

- Technical dimension: conception of the system value proposition from the individual contributions.
- Ecosystem architecture: conception of the operating model of the ecosystem with specific rules and roles.
- Financial dimension: business models and financial resources
- Contextual positioning: building legitimacy in the socio-cultural and industry-specific contexts

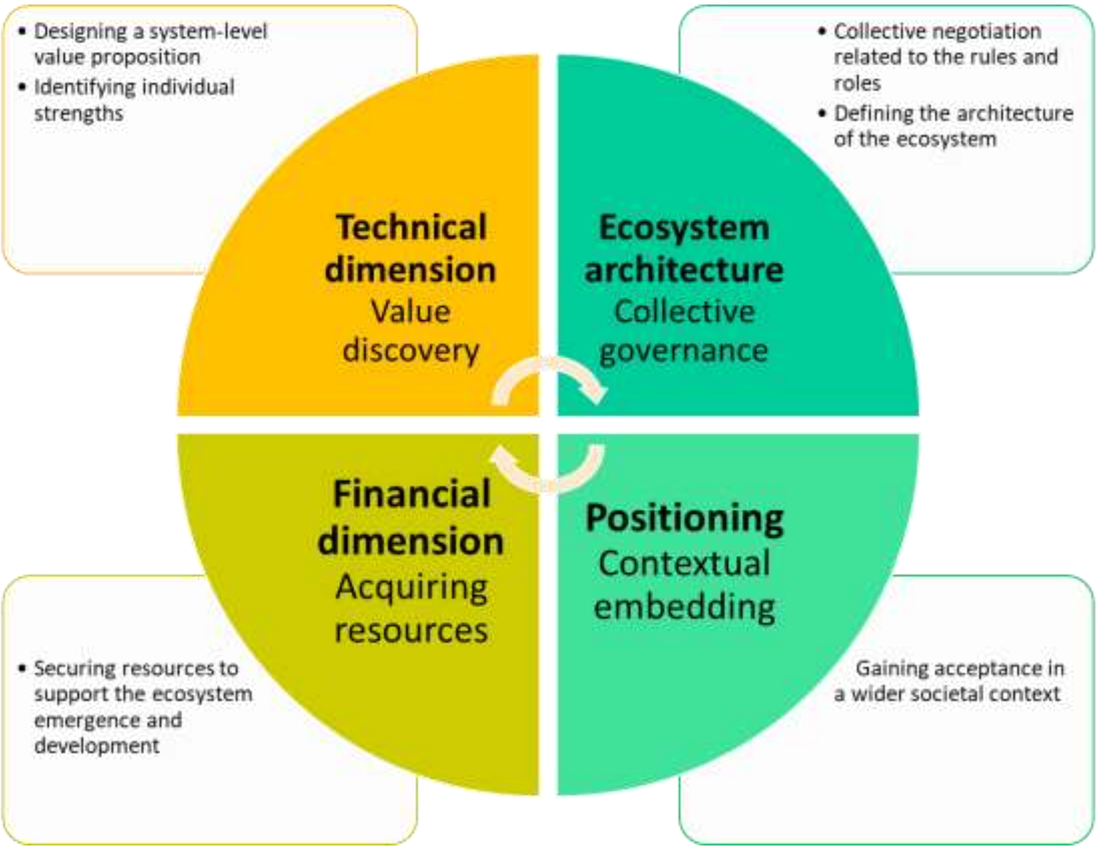

Figure 1. Processes of ecosystem emergence. Based Thomas et al. (2022)

1.5 Stages of ecosystem emergence

Each ecosystem emergence's stage from its conception to consolidation is crucial, especially in self-organized public-private ecosystems. First, in the *genesis* of ecosystems, initial actors informally lay the foundations and raise awareness about a problem to be addressed and possible collaborative solutions (Asplund et al., 2021). Subsequently, when the ecosystem is *launched,* defined, and formalized in terms of its objectives and the roles of the first members, the next step is about working in an orderly manner on the system value proposition.

When the structure becomes solid and the ecosystem gains recognition in its socio-cultural context, it would reach the third stage of emergence related to the *expansion*. Here, orchestrator and key actors would search for new members to sum resources and broaden the ecosystem scope. At this point, there would be a clear definition in terms of ways of working, roles, interfaces, and resources. Finally, the ecosystem would reach its consolidation when it can capture value and reach legitimacy not only at the level of the geographical context but also of the industry specific context where it is embedded (Thomas & Ritala, 2022). As the ecosystem emergence is an evolutionary process (Figure 2), Those actors planning the creation of ecosystems must consider the sustained efforts required over time to develop and consolidate the ecosystem structure (Asplund et al., 2021; Thomas et al., 2022).

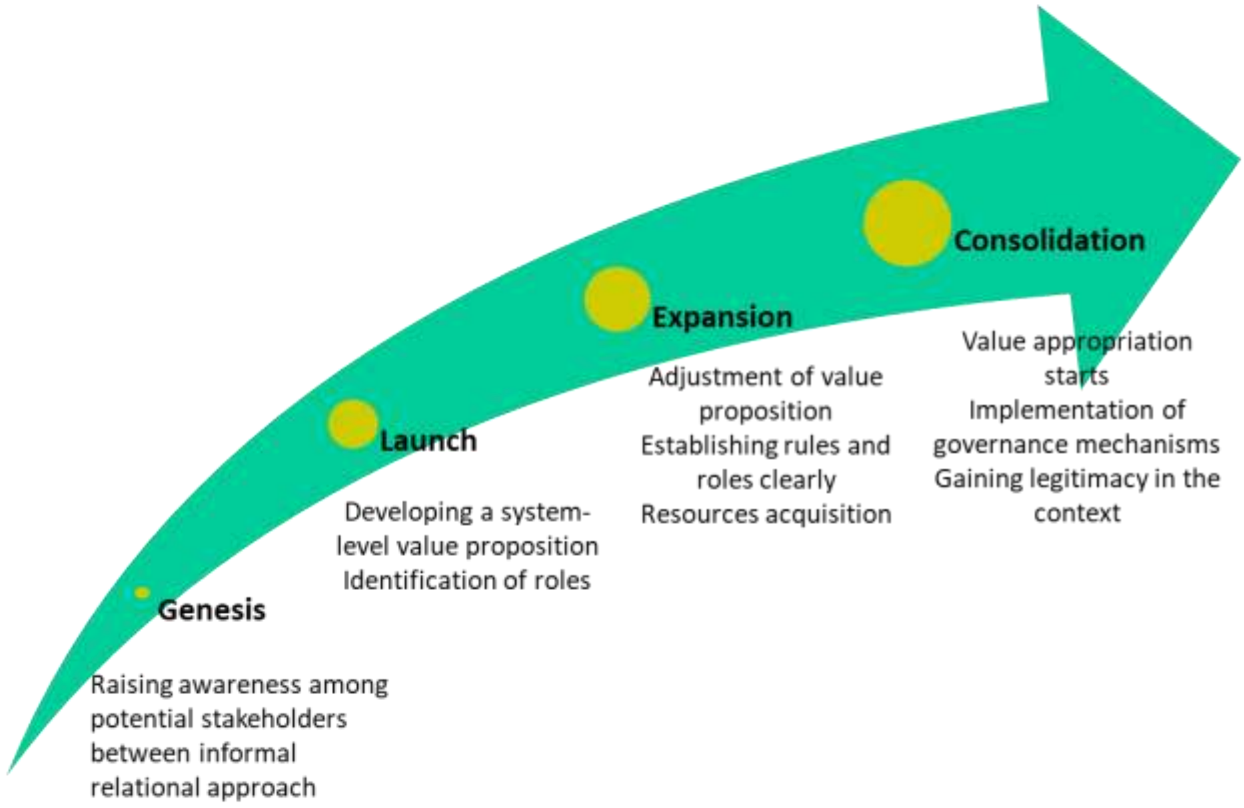

Figure 2. Stages of ecosystem emergence. Based on Asplund et al. (2021) and Thomas et al. (2022)

1.6 Roles of ecosystem actors

Currently, government agencies are turning to ecosystem structures as part of addressing the most complex social challenges. Ecosystems enable to join forces from different sides of society, such as the private sector or civil society, and achieve consensus (Addo, 2022). In particular, the interaction between government actors, industry, universities and research institutes, and citizens in ecosystems is gaining relevance in territorial development as the collective efforts speed up the necessary actions at the regional level. Furthermore, social benefits and economic value are achieved from the joint work of actors in creating solutions and disseminating and applying knowledge (Dos Santos, Zen, & Bittencourt, 2021).

The ecosystem perspective aims to generate relationships beyond the merely transactional dimension, where the commitment between entities becomes the axis of connection between shared capabilities and resources (Blasco-Arcas et al., 2020). Here, physical proximity enhances the interactions among actors within ecosystem structures, fostering the creation of socioeconomic value. This occurs through access to complementary resources and the development of relational resources, enabling ecosystems to emerge in specific geographical areas (Dos Santos et al., 2021). However, ecosystem actors can expand their networks outside the geographic perimeter, mostly when the ecosystem reaches maturity (Mazzucato & Robinson, 2020).

As for the role of public actors, it is related to providing the institutional conditions that influence and guide the ecosystem structure. These actors include territorial authorities, regulatory agencies, public funding entities; and depending on the country, academia and public research institutions could be part of the public side (Dos Santos et al., 2021). Actors in the academia would provide the qualification of human capital, dissemination of knowledge and technological development (Dos Santos et al., 2021). In terms of the private actors, industrial players could contribute to the transformation of knowledge into solutions. This group of actors could include large companies, start-ups, and private financiers. Finally, civil society actors can participate in ecosystems by offering a bottom-up approach to developed ecosystem solutions (Dos Santos et al., 2021).

The multi-stakeholder perspective in ecosystems allows regions to embark on alternative paths of innovation, exploring the creativity and resources of the actors based on a close geographical territory. Indeed, in relation to the challenges of the energy transition, self-organized public-private ecosystems provide transdisciplinary approach and solutions adjusted to reality (Dos Santos et al., 2021).

1.6.1 Orchestrator role

Orchestration involves managing innovative processes and resource mobility in the ecosystem facilitating the value creation and capture (Addo, 2022). The concept of orchestration has been defined by Still et al. (2014), as the exercise of guided transformation of an ecosystem structure to continuously evolve and create value. This includes exerting a subtle influence on the actors (Still et al., 2014).

However, interactions between members are complex because of the need to align individual and collective goals (Addo, 2022). According to studies by Isckia, de Reuver, & Lescop (2020), orchestration is carried out on two levels: first, managing the mobility of resources and their stability, and second, ensuring their sustainability and development over time. The role of leading ecosystems requires specific capabilities to influence ecosystem members to mobilize resources toward the fulfillment of the value proposition (Addo, 2022).

Orchestrators play key roles in the emergence and consolidation of ecosystems. For example, they act as 'architects' of the ecosystem structure and enable adequate resource mobilization (Addo, 2022; Mann, Karanasios, & Breidbach, 2022). Orchestrators also exercise arbitration functions to settle differences between the members of the ecosystem, guaranteeing the stability of the network (Addo, 2022; Mann et al., 2022). Likewise, they direct knowledge and resources to meet the established objectives. Furthermore, orchestrators commonly act as a link between the ecosystem and relevant actors or other wider networks (Addo, 2022; Mann et al., 2022).

Notably, orchestrators in self-organized public-private ecosystems should strive to balance potential power asymmetries among stakeholders (Mair, Gegenhuber, Thäter, & Lührsen, 2023). Managing plurality also needs a collaborative approach that encourages member participation and facilitates consensus-building (Mair et al., 2023).

1.7 Ecosystem mapping

Identifying ecosystem stakeholders is crucial for understanding their unique roles in the system's value proposition. It also helps define their interactions and contributions at distinct stages of ecosystem development. In the ecosystem stakeholder map proposed by Valkokari et al. (2021) based on the VTT report by Nousiainen & Vienamo (2019), it is possible to identify different stakeholder types in relation to their nature, for instance: public authorities, industry, academia, financiers, orchestrator, etc. (Figure 3). Moreover, stakeholder mapping in emerging regional ecosystems is also beneficial to identify active, passive or even potential members depending on their level of involvement (Valkokari et al., 2021).

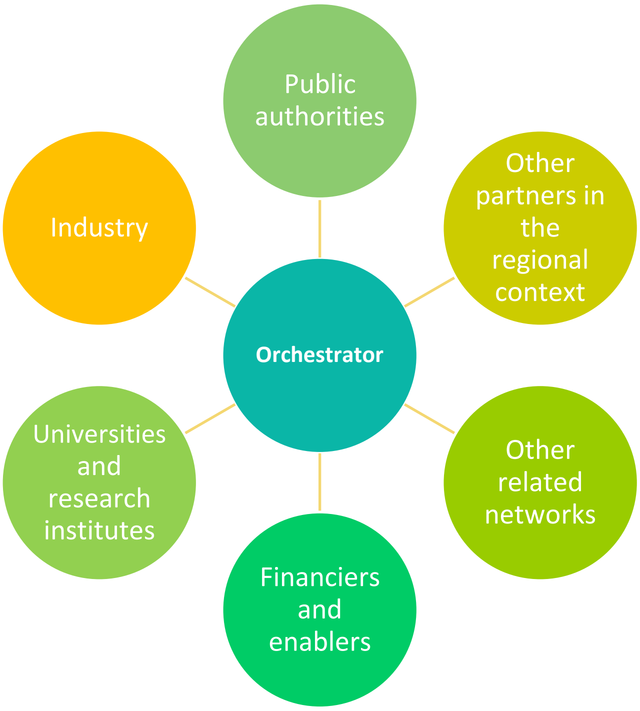

Figure 3. Ecosystem mapping. Based on Valkokari et al. (2021)

2 Hydrogen in practice: International benchmark

As stated by Bart Biebuyck, Executive director of the Clean Hydrogen Joint Undertaking in recent reports (Weichenhain et al., 2022), developing local conglomerates of hydrogen actors, along with shared infrastructure and joint supply sources, is crucial for scaling the clean hydrogen industry. These ecosystems, clusters, and hydrogen hubs perform a key role in fostering growth and efficiency within the sector. In the international landscape of hydrogen ecosystems, initiatives such as hydrogen valleys are gaining relevance as they enable scaling hydrogen production and create positive impacts across different sectors. For instance, hydrogen and its derivatives could contribute to the decarbonization of the mobility sector where battery electrification is not a feasible option. In the energy sector, hydrogen would appear as a new energy carrier to increase flexibility in terms of energy storage (Weichenhain et al., 2022).

On the international scene, hydrogen ecosystems could progressively transform into hydrogen valleys when reaching maturity, solid investment commitments and an integrated value chain approach. As per the Clean Hydrogen Partnership, hydrogen valleys are ecosystems that operate in a specific geographic location with a local, regional, national, or international scope. Hydrogen valleys are characterized by covering and integrating different segments of the hydrogen value chain such as production, distribution, storage, and use (Clean Hydrogen JU, 2024). Additionally, hydrogen valleys must meet a series of conditions in terms of scope and scale, for example, these initiatives show the versatility of hydrogen in the provision of products in more than one sector of the economy and cover multiple steps of the value chain. In terms of the scale, hydrogen valleys are required to be large enough in scale to reach at least two-digit multi-million EUR of investment and must show projects with considerable developments (Weichenhain et al., 2022). Currently, there are different hydrogen valleys initiatives identified all over the world, as can be seen in Figure 4.

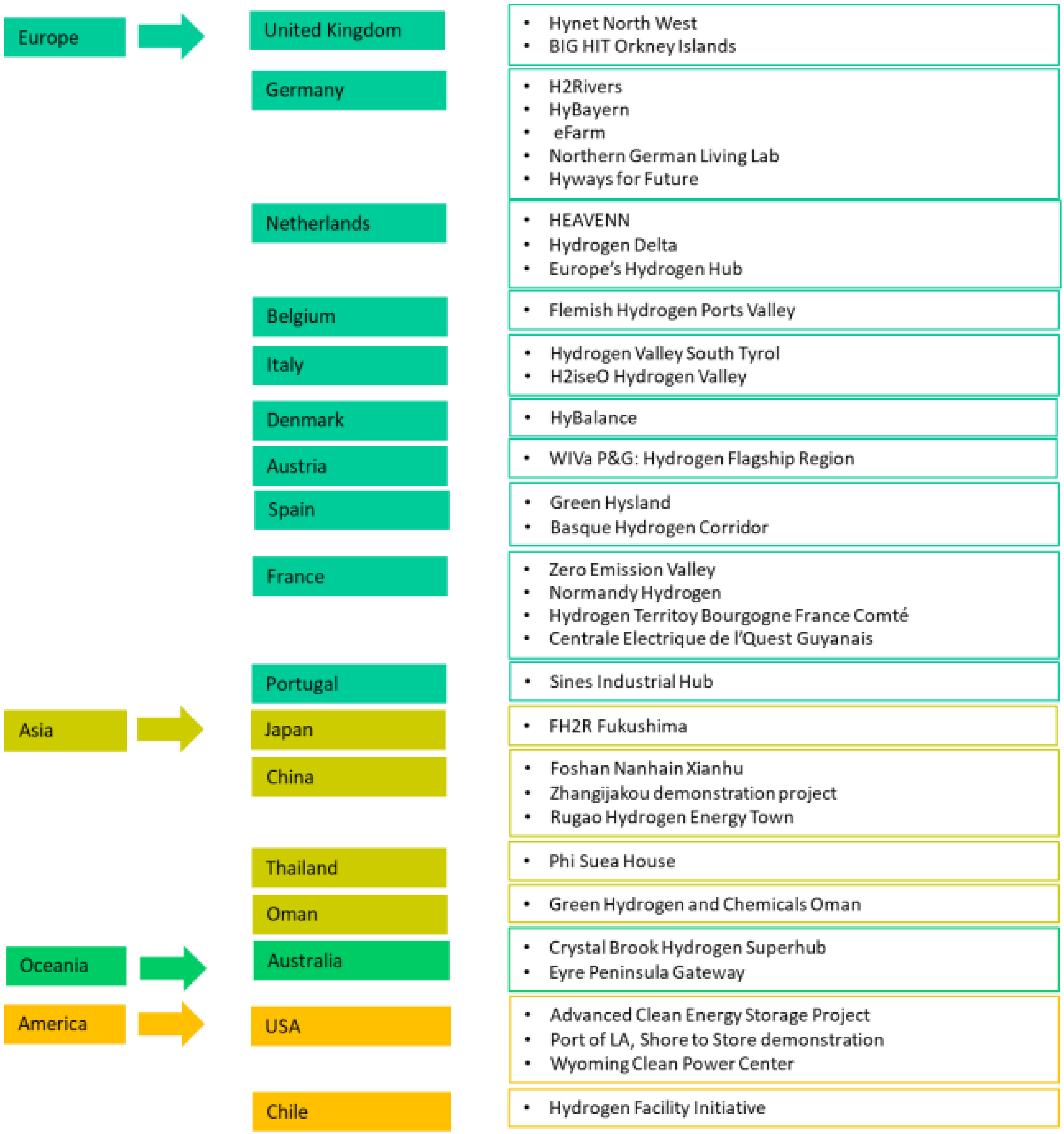

Figure 4. Current global hydrogen valleys activities. Based on Weichenhain et al. (2022)

According to the report by Weichenhain et al. (2022), hydrogen valleys around the world drive the decarbonization not only of the energy sector but of adjacent sectors. As can be seen in Table 1, the value chain coverage of hydrogen valleys includes the energy sector with applications of stationary fuel cells, gas grid injection, power generation and energy storage. Furthermore, these initiatives expect to impact solutions for the mobility sector in road transport, forklifts, ships, and trains. Additionally, industries such as steel manufacturing, refineries and chemicals are also included in these hydrogen valleys' scope. At the moment, Europe appears as the frontrunner in this matter due to the current EU political targets (Weichenhain et al., 2022). Nowadays, Clean Hydrogen JU provides funding for 18 hydrogen valleys in 17 European countries that together represent an investment of more than one billion EUR (Clean Hydrogen JU, 2024).

Table 1. Examples of hydrogen Valleys by production, investment, and value chain coverage (Weichenhain et al., 2022)

Hydrogen Valley	Location	H2 (tons/y)	Investment (EUR m)	Timeline	Hydrogen value chain coverage			
					Production route	End users	Storage	Distribution
eFarm	Germany	219	16	2017-2022	PEM electrolysis	Transport sector (cars, buses, trucks) Power sector		Road carrier
H2Rivers	Germany	380	50	2019-2023	PEM electrolysis	Transport sector (cars, buses, service vehicles)	Cylinder	Road carrier
Hyways for Future	Germany	1095	90	2020-2024	PEM electrolysis	Industry (steel) Transport sector (cars, buses, trucks, and others)	Cylinder	Road carrier
Norddeutsches Reallabor	Germany	4800	400	2018-2026	PEM electrolysis Alkaline electrolysis	Industry (chemicals, refineries, and others) Transport sector (cars, buses, trucks, and others)	Cylinder Cavern	Road carrier Pipeline
HEAVENN	Netherlands	36500	2800	2019-2026	PEM electrolysis Alkaline electrolysis Byproduct	Industry Transport sector (cars, buses, trucks, ships) Power sector (stationary fuel cells)	Cavern	Pipeline Road carrier
Europe's Hydrogen Hub: H_2 Proposition Zuid-Holland/Rotterdam	Netherlands	1160700	1000	2021-2030	PEM electrolysis SMR with CC(U)S	Industry (chemicals, refineries) Transport sector (cars, buses, ships) Power sector (gas-fired power plants, gas grid injection)	Cylinder	Pipeline
Basque Hydrogen Corridor	Spain	24600	3000	2020-2030	Alkaline electrolysis Solid oxide electrolysis	Industry (refineries, steel) Transport sector (cars, buses, trucks, forklifts, ships) Power sector (gas grid injection)	Cylinder Cavern	Pipeline Road carrier

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Green Hysland	Spain	300	50	2018-2025	PEM electrolysis	Transport sector (cars, buses) Power sector (stationary fuel cells, gas grid injection)	Cylinder	Pipeline Road carrier
Hydrogen Valley South Tyrol	Italy	90	55	2017-2026	Alkaline electrolysis	Transport sector (cars, buses, trucks)	Cylinder	Road carrier
Centrale Electrique de l'Ouest Guyanais	French Guiana	730	130	2017-2024	Alkaline electrolysis	Power sector (power generation, energy storage)	Cylinder	No information
HyBalance	Denmark	Confidential	15	2015-2020	PEM electrolysis	Industry Transport sector	Cylinder	Pipeline Road carrier
WIVA P&G: Hydrogen Flagship Region	Austria	3650	80	2018-2025	PEM electrolysis	Industry Transport sector (buses, trucks, trains) Power sector (stationary fuel cells, gas grid injection)		Road carrier Ship
BIG HIT	United Kingdom	Confidential	14	2014-2022	PEM electrolysis	Transport sector (cars) Energy (stationary fuel cells)		Ship
Shore to Store Demonstration Project	USA	Confidential	70	2019-2023		Transport sector (trucks, HRS, service vehicles)		
Eyre Peninsula Gateway	Australia	15000	150	Conf-2024	Alkaline electrolysis	Industry (off-take sectors confidential)	Cylinder	Pipeline Road carrier Ship
Crystal Brook Hydrogen Superhub	Australia	9000	370	2018-2024	PEM electrolysis	Industry (chemicals, refineries, steel, and others) Transport sector (cars, buses, trucks, trains, forklifts, ships) Power sector (gas-fired power plants, gas grid injection		
FH2R Fukushima	Japan	200	200	2020-TBD	Alkaline electrolysis	Transport sector (cars, buses) Power sector (stationary fuel cells	Cylinder	Road carrier

2.1 Finland moving towards hydrogen valleys

Currently, Finland also appears on the radar of the hydrogen valleys given the country's potential to become a strong contributor to the European hydrogen production goals. The country is characterized for the significant generation of green electricity with affordable prices, and strong cooperation ties with other Nordic and Baltic countries. Among the initiatives that are progressing with great force on the national and European stage are the BalticSeaH2 and the BotH2nia Valley. Both initiatives would benefit from the recent support that more than 50 million EUR in hydrogen approved by the European Commission in 2024 for the hydrogen transport infrastructure promoted by Gasgrid in the Baltic Sea (BotH2nia, 2025).

2.1.1 BalticSeaH2

BalticSeaH2 leads an innovative initiative to establish a prominent hydrogen valley across the Baltic Sea region, with a primary focus on southern Finland and Estonia. The project facilitates over twenty cases and more than ten investment opportunities, demonstrating the versatility of the hydrogen economy across multiple sectors (BalticSeaH2, 2024).

The Gulf of Finland provides an existing infrastructure foundation, including natural gas networks, electricity grids, and marine traffic, which the project leverages to reduce carbon emissions from current maritime operations. Gasgrid Finland is actively advancing hydrogen infrastructure through initiatives such as the Nordic-Baltic Hydrogen Corridor, the Baltic Sea Hydrogen Collector, and the Nordic Hydrogen Route. These efforts aim to drive significant development in the hydrogen economy and expand hydrogen markets across the Baltic Sea region (BalticSeaH2, 2024).

Among the investment cases included under the scope of the BalticSeaH2 hydrogen valley are:

- P2X Solution hydrogen plant in Harjavalta
- 3H2 Helen green hydrogen plant in Helsinki
- Green North Energy green ammonia plant in Naantali
- Neste renewable hydrogen plant in Porvoo

2.1.2 Both2nia Valley

The BotH2nia Hydrogen Valley is an initiative based on the collaboration of project developers, national and international companies, and research institutions in the West Coast of Finland. This hydrogen valley has an expected investment of more than 3 billion EUR from its eight value chains. In addition to the collaboration between companies located in Vaasa, Kokkola, Oulu, Pori, this valley is also linked with partnerships in Sweden, Estonia, France, Germany, Portugal, Bulgary, Lithuania and Chile (BotH2nia, 2024).

BotH2nia Hydrogen Valley projections indicate that about 99 ktpa of H2, 86.5 kton of e-methane, 64.2 tpa of e-methanol and 220.000 ktpa of green ammonia could be produced. These developments are expected to contribute solidly to the decarbonization of energy systems and industrial and transportation activities by replacing fossil fuels. It is also expected that a large number of jobs will be generated, and the experiences will serve as a reference for best practice in Europe (BotH2nia, 2024).

3 Hydrogen in practice: National benchmark

In the Finnish national outlook, different initiatives have appeared in recent years, both for collaboration between public and private actors, as well as specific clean hydrogen infrastructure projects. It is noteworthy to mention that clusters and associations are currently contributing significant efforts to build the pillars of the hydrogen economy in Finland. Identifying existing collaboration initiatives is a valuable source of social capital, allowing regional efforts to be aligned and their impact maximized.

Likewise, the Finnish clean hydrogen portfolio is also a central asset in this moment because it tangibly represents actions in favor of the decarbonization and flexibility of energy systems through the construction of infrastructure for the production, distribution, and use of clean hydrogen.

Although no clearly defined ecosystem initiatives were found in the national benchmark (with the exception of the project “H2 Ecosystem Roadmap for Ostrobothnia”, which has recently added to a hydrogen valley initiative and possibly the Ecogrid Energy Park in Pori), the clusters and forums are bridging a strong path for regions to create ecosystem initiatives with an attractive and achievable value proposition that results in environmental, social and economic benefits.

3.1 Hydrogen ecosystems initiatives, clusters, and associations in Finland

3.1.1 Hydrogen Cluster Finland

Hydrogen Cluster Finland (H2 Cluster Finland) brings together industrial players and associations that promote the clean hydrogen economy in Finland since 2021 through collaboration, information exchange and the creation of business opportunities. Members of this cluster include actors from the entire clean hydrogen value chain from renewable energy, production, distribution/transport, storage, and use (H2 Cluster Finland, 2024a). It comprises over 70 members of companies spanning the hydrogen value chain, along with six industry associations.

One of the significant contributions of this cluster is the production of studies on the development of the hydrogen economy in the country such as the "Clean hydrogen strategy for Finland" (2023), White papers as the "A systemic view to the Finnish Hydrogen economy today and in 2030" (2021), "Hydrogen economy education and RDI activities of universities and research institutes" (2022), among others.

3.1.2 Both2nia

BotH_2nia is a collaborative network of stakeholders dedicated to advancing hydrogen energy. Its primary goal is to establish a Nordic hydrogen cluster centered around the Gulf of Bothnia. BotH_2nia welcomes businesses, research institutes, investors, municipalities, and cities to actively contribute to building a greener future (BotH2nia, 2024).

In early 2024, BotH_2nia would evolve into a cooperative network connecting local hydrogen valleys in the northern Baltic Sea region. The network is open to organizations engaged in the hydrogen industry and related innovations, developers of commercial hydrogen projects, RDI (Research, Development, and Innovation) actors, educational institutions, financiers, municipalities, and public administrations from Sweden, Finland, and beyond (BotH2nia, 2024).

3.1.3 Hydrogen Research Forum Finland

The Hydrogen Research Forum emerged as a research-focused network in 2022 to support the open and independent dialogue and collaboration in hydrogen transition and research. The aim of this forum is to develop a comprehensive understanding of the current state of hydrogen research in Finland. It draws its strength from the experience of some of the leading Finnish universities and research institutes, as the Lappeenranta-Lahti University of Technology – LUT, University of Jyväskylä, University of Eastern Finland, Aalto University, Tampere University, University of Turku, University of Oulu, University of Vaasa, VTT, Luke among other members (Hydrogen Research Forum Finland, 2024a).

One of the recent outcomes released by the Hydrogen Research Forum was the so-called "Strategic Research Agenda for Finnish Hydrogen Research: Insights from the Hydrogen Research Forum Finland" (Hydrogen Research Forum Finland, 2024b). This document comprise the key research areas related to power-to-x technologies and the hydrogen economy in Finland and Europe.

3.1.4 The emerging hydrogen ecosystem in Ostrobothnia

The H2 ecosystem roadmap (for Ostrobothnia) was an initiative developed by three universities in Vaasa as Hanken School of Economics, Vaasa University of Applied Sciences (VAMK) and Novia University of Applied Sciences during 2021-2022. The objective of this project was to form a regional network of actors interested in green hydrogen and create a knowledge base about the role of hydrogen and new opportunities in terms of business, and the energy transition in the region (Koskinen, 2022).

This project highlighted the advantages of the region in terms of the hydrogen economy in the region, for example, the strong clusters of companies and organizations in energy, technology, automation, and components. Cross-sector collaboration and close synergy between industry, academia, and public sector were the ultimate goal of this project. The project presented a regional picture of opportunities for the local competition in hydrogen at international standards and export capacity in system level solutions (Koskinen, 2022; Penttilä, 2023).

3.2 Finnish hydrogen project portfolio

Currently, there are relevant Finnish initiatives developed for the production, use, transportation and provision of hydrogen and its derivatives. According to the information published on the H2 Cluster Finland website, there are more than 45 clean hydrogen projects (H2 Cluster Finland, 2025a, 2025b).

These projects accumulate an investment that could reach 25 billion EURO, to produce more than 1.300.000 tons annually H2 production from the planned projects. These projects add capabilities in clean hydrogen and derivatives such as green ammonia, e-methane, e-methanol, sustainable aviation fuel (SAF), and other solutions for power-to-gas/power-to-liquids (H2 Cluster Finland, 2025a) (Figure 5).

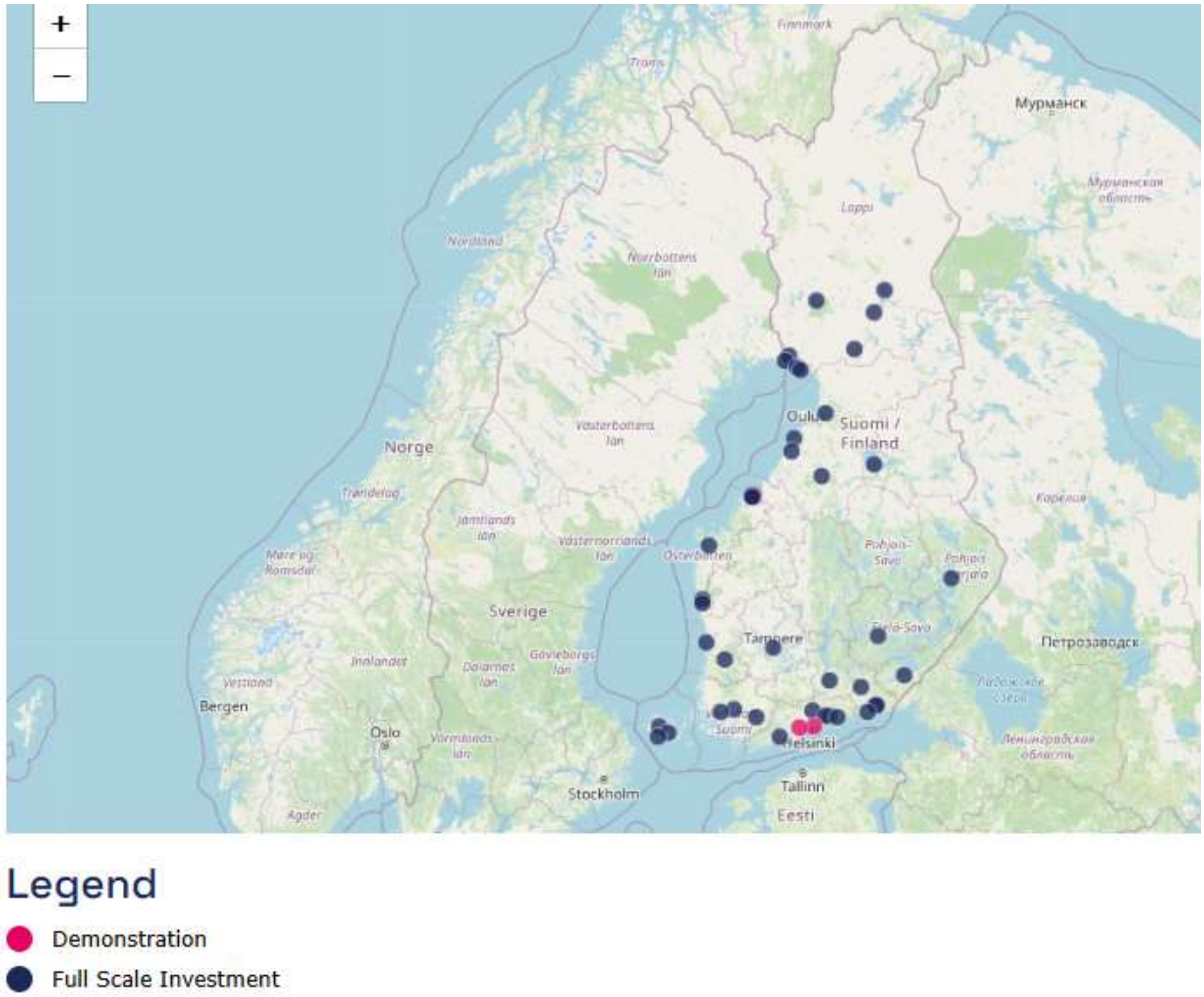

Figure 5. Clean hydrogen projects map in Finland – projects in full scale investment and demonstration (H2 Cluster Finland, 2025a)

This project's portfolio comprises initiatives of different scales which are expected to generate positively impact national energy systems in sectors such as maritime, agriculture, road transport, aviation, steel production, and as viable alternative to interchange with natural gas and biogas. Presently, organizations as P2X Solutions, Plug Power, Flexens and VetyAlfa are running significant projects in Finland as:

- P2X Solutions plant in Harjavalta. This green hydrogen plant has been one of Finland's most emblematic projects and a reference for national stakeholders in current initiatives (P2X Solutions Oy, 2023).
- Plug Power plant in Kristinestad. Green hydrogen in this facility is expected to be used in direct iron production (Plug Power, 2024).
- Plug Power green hydrogen plant in Kokkola. This plant would to produce liquid green hydrogen for local use and export and green ammonia for export (Plug Power, 2023).
- Flexens green hydrogen plant in Kokkola is integrating with green ammonia production (H2 Cluster Finland, 2024b).
- Vetyalfa green hydrogen refinery in Kemijärvi. From the green electricity produced in Lapioselkä, this refinery is expected to generate green hydrogen and synthetic fuels such as e-methane and e-methanol (VetyAlfa, 2024).

Abovementioned projects would benefit from the future development of the Nordic Hydrogen Route to build a cross-border hydrogen infrastructure in the Bothnian Bay region (H2 Cluster Finland, 2025a).

4 Conclusions

This study presents a benchmarking of hydrogen ecosystems based on literature and publicly available sources. The study first includes the key concepts from the literature on ecosystems emergence, from the definition, type of ecosystems, processes in emergence, stages, roles of actors and ecosystem mapping.

Subsequently, the study presents an international benchmark of initiatives based on public information from the main hydrogen agencies. Finally, the study illustrates about the Finnish national outlook from the collaboration initiatives in ecosystems, clusters, and associations, as well as the portfolio of the main infrastructure projects and actors in the country.

Based on the findings of this study, it can be concluded that ecosystems play an essential role as social structures that link both public and private stakeholders for the development of a common value proposition at a system level. The collaborative nature of ecosystems creates links of trust and reciprocity, which allow risk situations to be overcome, such as the scaling of innovations in the construction of the hydrogen economy.

The stages in the emergence of ecosystems should be addressed considering the processes of value discovery, collective governance, acquiring resources and contextual embedding. In the emergence of ecosystems, the definition of actors' roles and rules, especially the role of the orchestrator are key to driving the social structure towards its consolidation.

Hydrogen valleys appear in the international landscape as ecosystems that have reached an advanced level of maturity, large-scale hydrogen production and wide scope in the hydrogen value chain. Regarding the national landscape, clusters and forums created in the last years as the H2 Cluster Finland, H2 Research Forum Finland and BotH_2nia, are building synergies between actors around the country to support regional and local initiatives in clean hydrogen. Overall, current efforts across regions in Finland will lay the foundation for future growth of the hydrogen economy.

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