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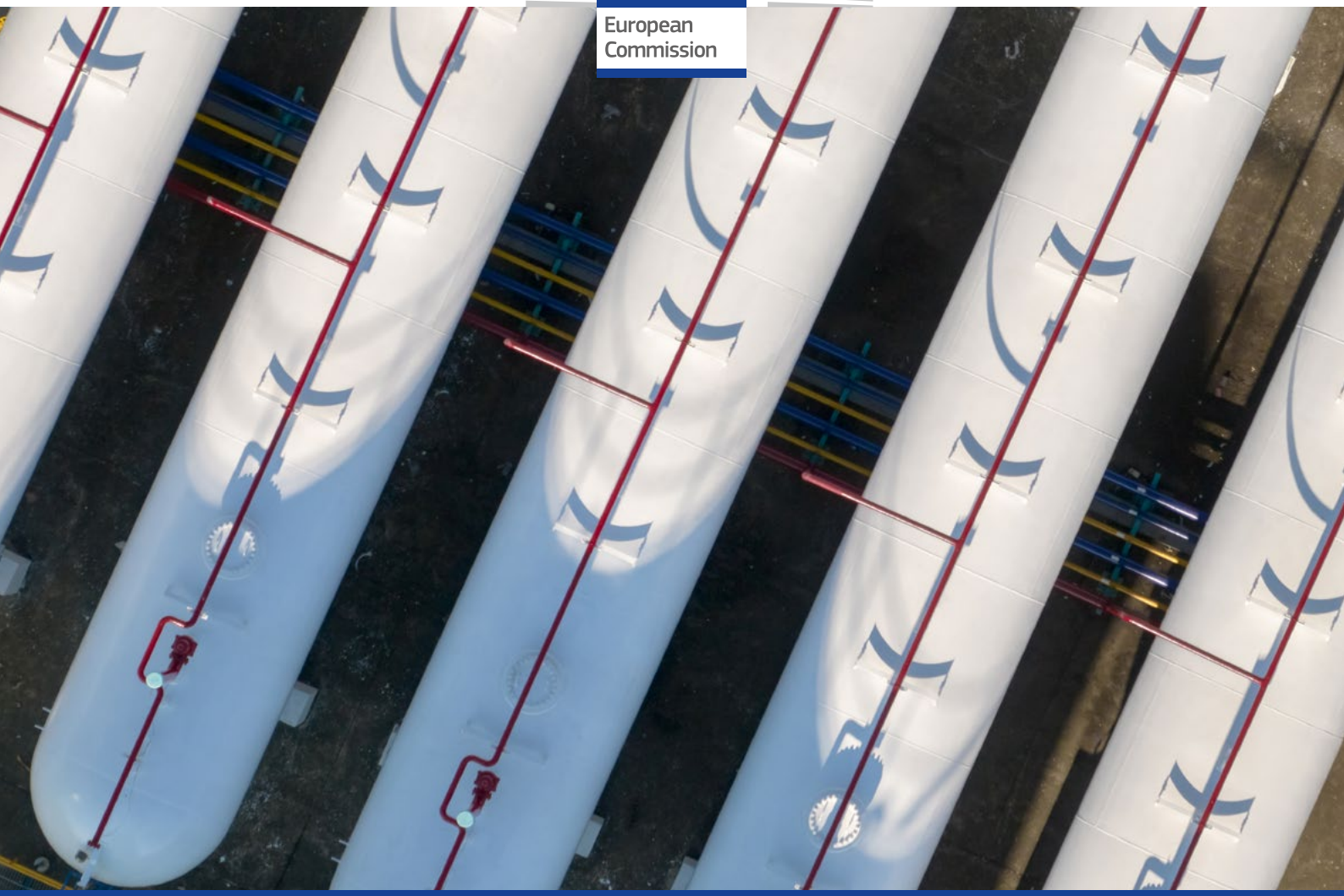

Supporting clean hydrogen development in Stara Zagora

A case study of hydrogen valleys in the Netherlands and Poland

Energy

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Table of contents

Introduction

This paper has been developed as part of the support provided to the Regional Economic Development Agency of Stara Zagora through the EU Coal Regions in Transition Initiatives technical assistance facility START. It is one of three reports exploring opportunities for economic development and diversification of Stara Zagora Region, within the context of the eventual phasing-out of fossil fuel-based energy generation, including cessation of lignite mining activities, and the decarbonisation of the economy. The accompanying two papers cover the development of sustainable agriculture and mechatronics.

The purpose of this paper is to share experiences from other regions on the creation of a functioning value chain for clean hydrogen. Clean hydrogen is a sector of particular interest for Stara Zagora Region and is consistent with the development of clean energy, which has been identified amongst the potential strategic priority areas for diversification of the local economy. To this end, the paper considers two regional clean hydrogen initiatives. First, the HEAVENN programme to develop a fully functioning green hydrogen chain in the Northern Netherlands and, second, the development of a hydrogen ecosystem in the Eastern Wielkopolska region of Poland.

The paper has been developed using a combination of desk-based secondary research and interviews with *inter alia* local stakeholders and representatives of the two initiatives covered by the report. It provides case study descriptions of the Dutch and Polish hydrogen development trajectories, addressing topics such as the organisational setup, funding, and the consecutive steps for implementation. Further, lessons relevant to the Stara Zagora Region are drawn from both case studies and an outline of a potential roadmap is provided to move forward with the development of clean hydrogen in the Region.

The report is structured as follows:

- **Section 2**: describes and provides findings from the Dutch case study (the "HEAVENN" programme).
- **Section 3**: describes and provides findings from the Polish case study (the "Wielkopolska" project).
- **Section 4**: provides recommendations for Stara Zagora Region, including a roadmap for development of clean hydrogen in the region.
- **Annex**: contains persons of interest for the HEAVENN and Wielkopolska initiatives. **This information is not included in the public version of the report**.

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Case study: HEAVENN (the Netherlands)

What is HEAVENN?

Goals

The goal of HEAVENN (www.heavenn.org) is to develop a regional hydrogen energy system in Northern Netherlands, a so-called hydrogen valley that contains the full value chain of hydrogen, from production, distribution, storage to (local) end use. It is intended as a demonstration project, meaning that the amount of hydrogen moved through the chain is large enough to test the viability of each individual link in the chain and their interdependencies. With HEAVENN, the promoters wish to develop replicable business models for large scale commercial deployment of hydrogen, that can act as a blueprint for other hydrogen valleys.

Initiation

The HEAVENN Initiative has a duration of five years, starting in January 2020 and running until December 2025. However, because of COVID-19, many projects within HEAVENN faced delays in the first few years and so the various partners of HEAVENN are looking into the possibility of extending the project by two years to 2027.

It is difficult to pinpoint when the idea of HEAVENN was first conceived. Relatively early on, hydrogen was identified as a promising technology for Northern Netherlands, with several hydrogen-related projects being initiated. However, the use of several hydrogen buses in regional public transport is seen by several stakeholders as being important for accelerating the idea of creating of a hydrogen valley which led, in turn, to the creation of HEAVENN. The use of hydrogen buses brought several potential partners together, with the first activities to develop this network expand it into a full value chain beginning in 2017. In the years leading up to 2019 additional partners were contacted, funding was secured, projects were defined and a grant application for Horizon 2020 was written. In 2019 it was announced that HEAVENN had secured a grant of 20 million euro.

Creation of HEAVENN

Lead up

Historically, production and transport of natural gas made up a large part of the economy of Northern Netherlands. However, with the Paris climate agreements and recurring earthquakes as a result of the natural gas production, the national government decided to reduce and eventually stop the production of natural gas in the region. In this context, early plans for a hydrogen valley in the Northern Netherlands had been making their rounds among different parties for several years before HEAVENN was established.

The first hydrogen developments and the creation of a network of interested participants in the region that eventually led to HEAVENN were centred around the semi-autonomous and joint public transport company of the regional governments of Groningen and Drenthe. Since 2017, this public transport company was participating in European pilots for the development and operation of hydrogen buses. A first seed for HEAVENN was introduced when the public transport company tasked the company New Energy Coalition with expanding the fleet of hydrogen buses and developing the required infrastructure.

Horizon 2020 and finding partners

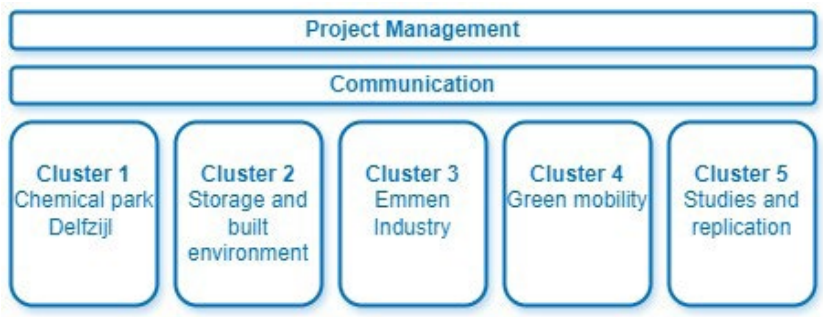
The development of the hydrogen valley received a boost when a call for the Horizon programme of the European Union was announced. This call offered a subsidy of twenty million euro for the development of a hydrogen valley. The hydrogen valley was to demonstrate the full hydrogen value chain. This means production, transportation, storage and consumption of hydrogen (in at least two different economic sectors).

New Energy Coalition took the lead in applying for the grant. They already had the relevant connections in the region, experience of the hydrogen sector, and familiarity in applying for European grants. New Energy Coalition started to enumerate the requirements for the grant and to look for the different partners that were necessary, able, and willing to participate. First, the national and regional governments needed to support the project. Next, several private companies in the area needed to join to provide individual links in the value chain. Additionally, the national gas grid operator needed to join, as they are by far the most knowledgeable authority on transmission and distribution of gases in the Netherlands. Also, several knowledge and research institutions were required to meet the research and educational requirements of the grant. Finally, several international partners were required, to make HEAVENN a European wide project and to meet requirements for knowledge dissemination and aiding other hydrogen valleys.

Defining a narrative

To convince potential private parties to join the Initiative and to persuade the regional and national government to provide additional subsidies, New Energy Coalition engaged with many institutional and private actors to discuss potential projects. To help sell the idea of the hydrogen valley, they created a narrative of two main arguments.

FIGURE 1: OVERVIEW OF HEAVENN WORKFLOWS



Source: Interview with Hydrogen Architects

The first argument was of an economic nature. It stated that hydrogen was the perfect fit for the region's declining economic potential because of the reduction in natural gas production. The region contains a wealth of knowledge about, and infrastructure for, handling molecules. With (relatively) minor adjustments, this part of the economy could be utilized to produce hydrogen.[1]

The second argument was technical in nature. The electricity grid in the Netherlands is under stress. A major increase in production and demand of electricity from renewable sources having pushed the grid to its limit of its capacity and unable to transport all the electricity, resulting in congestion. Therefore, hydrogen can be used to relieve the grid, converting electricity to hydrogen ("canned electricity") that, in turn, can be transported through pipelines and tankers or stored relatively easily.

Designing HEAVENN

New Energy Coalition was able to persuade sufficient parties to join HEAVENN, ensuring that it included a project covering each link in the hydrogen value chain. Additionally, the regional and national governments were convinced to double the grant of the European Union. With a core team, New Energy Coalition wrote the successful application for the Horizon 2020 grant, while creating a consortium of over thirty parties. Nonetheless, it fell to New Energy Coalition to combine all the different projects to form a single hydrogen valley. Achieving this meant that New Energy Coalition had to make adjustments, sometimes unilaterally or without extensive discussion, to individual project proposals.

The announcement of the successful award of a grant to HEAVENN was made in 2019, with the project commencing on January 1st, 2020, and running for five years to December 31st, 2025.

Organisational structure

Each major component of the hydrogen value-chain (production, transport, storage and consumption) is addressed in HEAVENN, making it a demonstration of the full chain. This hydrogen chain is fully integrated in the 'normal' economy of the region, demonstrating its functionality in day-to-day operations. The scale of the projects is sufficiently large that economies of scale can be achieved, and improved business models can be developed.[2]

Consortium working

The 31 parties involved in HEAVENN formed a consortium and signed a consortium agreement to that effect. This agreement stipulates the cooperation between the signatories. It also contains two clauses of particular importance. First, that when a partner wishes to leave HEAVENN, they have to introduce a replacement. And second, that the projects that are part of HEAVENN are not allowed to have other commercial dealings with other parties.

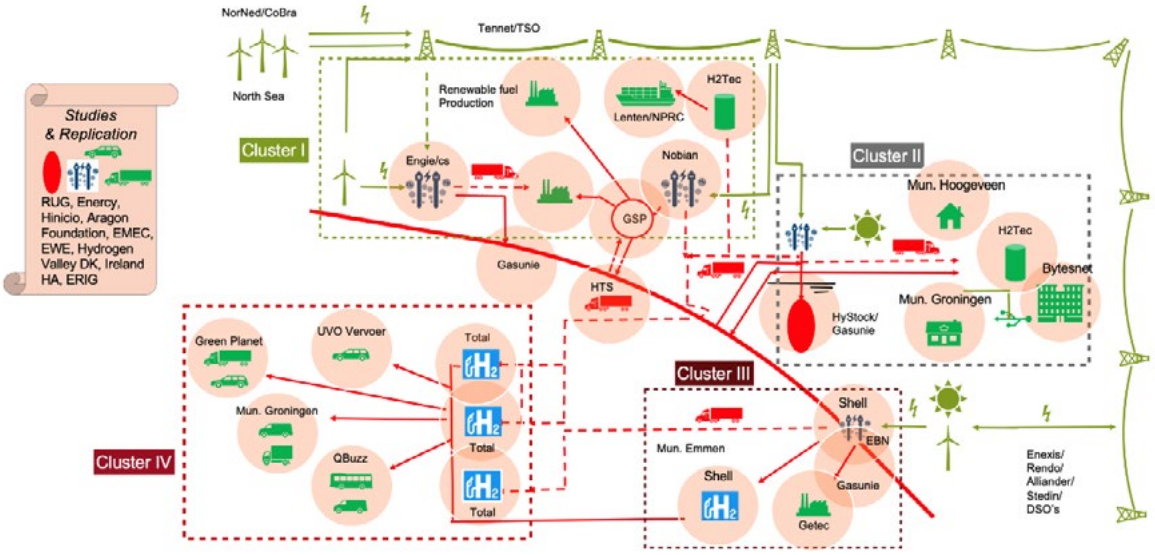
Additionally, all partners signed a grant agreement. This agreement stipulates the work and activities which each project and partners must carry out. Within the consortium each partner aims to fulfil their own project goals. While the combination of their activities fulfils the overarching goals of HEAVENN.

Periodically, a partner meeting is organised by New Energy Coalition. In this meeting the progress of the HEAVENN is discussed and required changes to the grant and consortium agreement are decided upon. Officially, every partner of HEAVENN has an equal vote and changes to individual projects need to be voted on. Practice shows, however, that these changes are usually a foregone conclusion.

1. Based on an interview with Hydrogen Architects, the designer of HEAVENN.

2. From the website of HEAVENN (accessed 05-04-2024) link

FIGURE 2: DESIGN OF HEAVENN



Source: HEAVENN website[3]

Workflows and clusters

HEAVENN is divided into seven 'workflows' (Figure 1). The first two workflows are project management and communication. The other five are the four regional project clusters and a final cluster for 'studies and replication'. Each workflow has a project leader, usually one of the organisations within the cluster. Project management and communication are done by New Energy Coalition.

HEAVENN is a collection of 23 different hydrogen related projects, which combine to form a complete value chain (Figure 2). The 23 projects are divided into four regional clusters:

1. **Chemical Park Delfzijl**: located at the chemical park of the city Delfzijl, the cluster consists of four projects. These projects facilitate the electrolysers of the Djewel 1 and 2 projects and the SkyNRG green kerosene production plant. This cluster also includes the implementation of a trailer outlet, enabling green hydrogen to be loaded on trailers and hydrogen powered inland barges.
2. **Storage and built environment**: located around the municipalities of Veendam, Hoogeveen and Groningen. In Veendam, an underground salt cavern is adapted to store hydrogen. In Hoogeveen, a neighbourhood is being prepared for heating their homes with hydrogen. And in Groningen, a datacentre will utilize a hydrogen power cell to power their emergency backup power generator.
3. **Emmen industry**: the cluster covers a gas treatment plant converted to produce 4 MW of green hydrogen. Transportation of hydrogen through a newly constructed pipeline to a gas turbines that is adapted to hydrogen and, additionally, construction of a hydrogen refuelling station is serving several hydrogen buses.
4. **Green mobility**: covering several mobility related projects scattered over the region including four hydrogen refuelling stations for heavy duty vehicles. Additionally, the province of Groningen and public transport company Qbuzz will employ almost 140 hydrogen vehicles, ranging from passenger vehicles to waste collections trucks and long-range buses.

There is also a fifth cluster, 'Studies and replication', which is tasked with studying and collecting best practices from HEAVENN projects and translating them into a model for showcasing and replication to other regions.

Resources

The resources required for HEAVENN are divided into three classifications: Funding, physical requirements, and expertise.

Funding

The total costs of HEAVENN are estimated at EUR 100 million, covering all the seven workflows. The European Union contributes EUR 20 million through the Horizon 2020 grant. The national government contributes EUR 10 million euro, as does the combination of three regional governments. The remaining EUR 60 million is provided by the private partners of HEAVENN.

3. https://heavenn.org/about/

When applying for the Horizon 2020 grant, New Energy Coalition established a budget and breakdown by partner. The budget was based on detailed costings from each partner proposing a project and an allocation key. The allocation key used was in line with EU guidelines. Private companies could receive up to 15%-25% of their (eligible) costs. SME's could receive a bonus of up to 15%, so in total 30%-40% of their eligible costs. Research institutions were allocated 50% - 100% of their costs.

Location assets

Northern Netherlands has several characteristics conducive to the creation of a hydrogen valley. Although none of these characteristics are essential for starting the development of a hydrogen valley, being able to incorporate certain elements in HEAVENN may speed up the development of the hydrogen valley the ecosystem that ultimately requires each link in the hydrogen value chain needs to be put in place. These characteristics include:

- The proximity of the region to the sea means that renewable energy from offshore wind parks for electrolysis is readily available.
- The region contains sufficient customers for hydrogen that an increase in production is warranted. For a while it is possible to keep production and demand balanced in the region, while the ecosystem matures. When the ecosystem is a bit more developed, it can connect to other hydrogen valleys and networks further away.
- The harbour of Eemshaven is a large container port, which offers possibilities for the cheap transportation of hydrogen.
- Northern Netherlands has traditionally been a hub for natural gas production and transportation. The region has a highly developed infrastructure for transporting gas. A part of this network could (relatively) easily be adapted to transport hydrogen. First within the region itself, but next to the rest of the Netherlands or abroad.
- The presence of empty salt caverns in the region made it possible to utilise one of them for hydrogen storage. This natural cavern is airtight and able to hold hydrogen without leaks.
- The region has sufficient physical space for the required technical installations, such as electrolysers and electricity infrastructure.

Expertise

Even though hydrogen production at large scale is largely unexplored territory, Northern Netherlands contained knowledge and expertise relevant for HEAVENN. As with the physical requirements, it would not seem that the presence of expertise on all aspects of the hydrogen value chain is essential for starting a hydrogen valley. However, at some point it is required and having access to it makes the development of the valley easier. In the Northern Netherlands the following expertise was present for HEAVENN:

- Several chemical companies are used to producing and handling hydrogen as a byproduct of chlorine production.
- Since 2015, a collaboration of a research institution, university, and university of applied sciences is researching and testing development in hydrogen.
- As a major producer of natural gas in northwest Europe, the region contains a wealth of knowledge and experience in handling and transporting gases.

Future development: ambitions and roadmap

HEAVENN is slated to run until December 2025. no continuation of HEAVENN as a project is foreseen at this moment, although some efforts are made to extend the project. A successful end of HEAVENN will mean that a hydrogen economy will have been developed in the region, which is of sufficient scale to have been tested in practise and can act as catalyst for further development and strengthening of the wider hydrogen valley.

Not all HEAVENN projects are expected to be fully successful, as COVID-19 and resulting shortages, together with the energy crisis following Russia's invasion of Ukraine, led to some setbacks. Nonetheless, the overall goal of creating a hydrogen valley seems set to be successfully realised. HEAVENN still has at least a year and a half to run but already various large and small hydrogen related activities are starting up, thanks to the creation of a functioning hydrogen ecosystem in Northern Netherlands.

The next step for the region will be to develop the valley further in two directions.

Strengthening the regional ecosystem

The first direction of development is to strengthen the regional ecosystem. HEAVENN is designed to contain a single entity for each link in the hydrogen production chain. And while parallel to HEAVENN other hydrogen companies have started up, more entities fulfilling the same roles are required to create a robust and sustainable ecosystem.

However, to become a fully established ecosystem, the production of hydrogen needs to be scaled-up significantly. The amount of hydrogen produced in a fully established hydrogen ecosystem is several orders of magnitude larger than currently produced in the ecosystem, which is in the demonstration phase.

Especially, much larger quantities will be required for potential industrial users to make the switch to hydrogen and costs of production will need to fall (see Box: The cost of green hydrogen). In this regard, the leap from demonstration phase to fully established system producing hydrogen at an industrial scale is likely to be too large to make in a single step. Making the necessary investments to raise production is inevitable hazardous in the absence of established market demand.

In this context, one of the main areas identified for further development is the mobility sector, which is the most developed hydrogen sector in Northern Netherlands. The region contains several refuelling stations and several hundred vehicles. The use case of hydrogen has been proven in the mobility sector and is therefore easier to use as foundation for further development. The amount of hydrogen required to scale up the mobility sector is seen to offer a 'sweet spot' is between the current produced amount and what is needed in a full ecosystem. Accordingly, stimulating the mobility sector to switch to hydrogen could allow production to expand in step with demand, gradually bridging the gap towards meeting industrial scale capacity.

Connecting with other valleys

The second direction in which the hydrogen valley needs to develop is through interconnectivity with other valleys. A single valley remains vulnerable and is unlikely to reach the mass required to achieve efficiencies of scale. Additionally, a single valley is unlikely to develop a proper market for hydrogen. So, hydrogen valleys need to connect to each other, creating an (inter)national hydrogen flow. To that end, a hydrogen backbone is being developed in the Netherlands, connect the northern Netherlands hydrogen valley to other hydrogen ecosystems in the Netherlands such as the port of Rotterdam and a cluster of chemical companies.

Further plans extend this backbone to regions in Belgium and Germany. Meanwhile, several other international connections are envisaged to link the Netherlands to hydrogen valleys in Spain, France, Italy, Scandinavia, Danube countries and the Baltics.

The cost of green hydrogen

The green hydrogen value chain is under rapid development. At this moment the price of hydrogen is still high. Companies struggle to create a solvent business case without financial aid. Prices of hydrogen are, however, expected to drop considerably over the years due to several reasons. First, techniques to produce hydrogen are still under development. As development continues, more efficient techniques are likely to be found. Second, the cost of parts for production equipment will fall. As the hydrogen market grows, so will the demand for equipment. Producers of the equipment can optimise their production process and produce in bulk, lowering the overall cost per part. This effect is mainly expected for the stacks of electrolysers. Third, the price of electricity is a large part of the price of hydrogen. As more renewable electricity is produced, the price should drop.

In the meantime, hydrogen companies indicated two ways in which the (various levels of) government can support them. First, through direct financial aid allowing companies to reach a financial break-even point. Secondly, the government needs to commit clearly and firmly to hydrogen. When the government commits to hydrogen, and backs this commitment up with policies, it creates stability and trust. Companies are willing to make investments if they believe that they will make a return on these investments. Stable long-term policies of the government lead to a longer time in which the return of investment can be earned.

The crucial role that governments take in the development of a hydrogen valley was recognised when creating HEAVENN. In two ways HEAVENN played into this. First, three regional governments were included as equal partners in HEAVENN. This made discussion about financial aid (slightly) easier and signalled to other companies that the governments take hydrogen seriously. Second, great efforts were made to embed hydrogen as the solution in opposition to natural gas in the public conscious. The narrative around hydrogen was carefully crafted and expressed diligently. Additionally, several high-profile projects led to an acceptance and embrace of hydrogen by the public in their environment. The embrace of hydrogen by the public makes it easier for the government to embark on a pro-hydrogen course.

The wider hydrogen valley in Northern Netherlands

While HEAVENN is a comprehensive hydrogen ecosystem, it is not synonymous with the hydrogen valley in Northern Netherlands. Throughout the creation and executing of HEAVENN many other projects, developments and activities were deployed in the region. All the efforts combined, including HEAVENN, make up the hydrogen valley.

The aim of the national government and various regional governments is to develop the whole region. To that effect, an investment agenda was published in 2019 by a coalition of regional government and private companies, promising to invest in hydrogen projects in the Northern Netherlands. Combined, these investments add up to over EUR 2 billion over the period 2019-2030. The authors of the investment agenda expected these investments to support the retention of 66.000 existing jobs, with the creation of 25 000 new jobs by 2030 and 41 000 by 2050. In 2020 an updated version of the investment agenda was published, in which the potential investments in the region by 2030 increased to over EUR 9 billion.

It is not possible to determine if a hydrogen valley in could have developed Northern Netherlands without HEAVENN, or which activities can be attributed to a spin-off effect of HEAVENN. However, it is certain that hydrogen companies that are not in HEAVENN are investing in the region. Moreover, the updated investment agenda praises HEAVENN as the flagship project of the hydrogen valley. Additionally, it praises the 'triple helix' approach of HEAVENN, where governments, private companies and research institutions collaborate to create an integrated value chain for hydrogen.

Key lessons

The HEAVENN initiative/programme has been running for over four years, allowing key lessons to be identified from the creation and execution of the programme to date, and from the implementation of projects within the programme. These are summarised in this sub-section.

Initiation and partnership-building

- **Be proactive, be open, and share your knowledge** when you are dealing with (potential) programme partners. The promoter needs to bind multiple partners to the programme. This is a complicated process and is more easily achieved when everything is kept transparent and easy.
- **Create a narrative that supports the creation of the project** and that is evidence based. The narrative must appeal to potential private and public partners – *what is the 'business case' for their participation?* – and should be tailored to the regional context. HEAVENN had a twofold narrative. First, creation of a hydrogen valley offers many economic and employment opportunities within the ecosystem. Secondly, hydrogen is the perfect fit for a region that has decades of experience in natural gas. According to the designer of HEAVENN, both parts of the narrative were supported by studies.
- **Involve (a few) large companies able to fulfil core functions and act as an engine for the partnership**. Developing a new ecosystem of companies is difficult and takes a long time. Large companies have the type of resources to commit to a large-scale project that SME's and start-ups do not. Having large companies occupy a few key functions of the ecosystem, creates a core that others can trust to stay invested. Then, other activities can develop from that core of base activities. When HEAVENN was conceived, there was no ecosystem in the region, but a core was formed by Shell and Nubian as producers and Gasunie as distributor.
- **Involve regional and national governments as partners in the programme**. Local, regional and national governments have a large role to play as they can help project with financial or legislative aid. In HEAVENN, regional governments are partners in the consortium. This has two advantages. First, it allows for closer cooperation with the government. Second, it signals the political intent of the government to support the hydrogen valley, which translates to stable policy towards hydrogen companies.

Project management and organisation

- **Stimulate potential partners to draw up detailed plans at an early stage**. A detailed programme/project plan is required when applying for EU funds and so needs to be done anyway, but the planning process also forces partners to think about what they want they want to do, how they are going to do it, and how much money they need. Clarifying these issues early on builds a shared common vision and expectation of partners. For HEAVENN, early planning would have made the articulation of the programme components much clearer, and much sooner.
- **Ensure continued participation of partners**. Building a hydrogen ecosystem requires the participation of multiple partners to ensure all roles can be filled and the ecosystem to survive and flourish. Partners must be able to trust that others in the ecosystem fulfil the role they need them to fulfil. When partners can opt out of the

ecosystem at will, this trust is difficult to develop. HEAVENN solved this issue by including a clause in the consortium agreement requiring partners wanting to opt-out of HEAVENN to introducing an alternative party to fulfil their role, thereby ensuring all roles in the ecosystem are always filled.

- **Be aware of the administrative burden on the programme leader and project partners**. Public financial support can entail substantial administrative burden, and programme leader should try to minimise the burden of project partners in as far as possible. In the case of HEAVENN, some projects spend significant time and effort in meeting the administrative requirements of the EU Horizon 2020 grant. Additionally, administrative demands can change over time, causing additional burdens for project partners.

Financing and financial management

- **Availability of public financing support is an important catalyst** for programme partnership formation. The availability of financial support from the Horizon 2020 programme was invaluable for the creation of HEAVENN. Hydrogen is not yet economically (commercially) viable and would not have gone ahead without a public subsidy, initially under Horizon 2020 and later complemented by Hydrogen Europe and Hydrogen Europe Research. Equally, the deadline for applying for Horizon 2020 support created a pressure cooker effect in which compromises and deals bringing the partners together were agreed that could have taken significantly longer, otherwise.
- **Be familiar with EU and national legal frameworks for public (state) aid**. It is important to understand EU and national rules and regulations concerning public (state) aid. These stipulate how much subsidy can be granted and how it should be spent. For several projects in HEAVENN the national and EU laws interacted in an unforeseen way, making it difficult for the regional government to financially support the projects. This led to delays and additional costs. It could have been prevented if the allocation of funds from the different levels of government had been pre-designed with this in mind.
- **Pay attention to the financing of operational costs (OPEX)**. Public financial support may be in the form of an investment-based grant, which means it only covers part of the initial investment costs. However, OPEX of the projects are an important part of the puzzle to create a sustainable ecosystem. In the case of HEAVENN that was designed as a demonstration project, Horizon 2020 support was only for the investment component. Accordingly, it would have been valuable if (part of) the financial support coming from elsewhere (e.g. national and regional/local government) was able to cover OPEX.

Policy framework

- **Public administrations should maintain stable and consistent policies and communications**. Creation of a functioning a new hydrogen ecosystem, requires business to make significant investments in the new technology and innovation. Companies are economically driven and will refrain from investing if they cannot get a return on their investments, so it is important that governments provide companies with the assurance that policies will remain supportive over the longer-term and communicate on their commitment to supporting development of the hydrogen ecosystem.

Case study: Eastern Wielkopolska (Poland)

Introduction

This case study covers the development of a local hydrogen market led by ZE PAK SA in Eastern Wielkopolska[4], where the company's main original assets — lignite mines and power plants — are located. It should be noted that although ZE PAK SA hydrogen-related activities can be considered as pertaining to the creation of a hydrogen valley, they do not equate with the definition of a hydrogen valley the Polish Hydrogen Strategy adopted in November 2021.

Hydrogen ecosystem in Konin (Eastern Wielkopolska region)

Context

The development of the hydrogen ecosystem in Konin was driven primarily by the divestment and portfolio diversification targets adopted by ZE PAK. Since mid-2010, the company has endured rising cost of lignite production and related power generation, largely due to EU regulations (e.g., EU ETS, BAT, and others). To break-away from this situation, the company decided to gradually shut down the least profitable of its mines and power plants, aiming to end coal use by 2025 under its current scenario. At the same time, ZE PAK used the opportunities provided by various European policies, such as support for low- and zero-emission technologies, to begin transitioning from coal to green energy. To this end, the company decided to hedge its risks by investing in three areas of green technologies: (1) Renewable Energy Sources (solar and wind farms); (2) hydrogen production based on biomass and construction of fuelling stations; and (3) green transport (production of hydrogen buses).

In 2018, ZE PAK created the first two projects aimed at decarbonising its energy production. The first project aimed to repurpose one of the lignite boilers used in the ZE PAK power plant to burn biomass (50 MW). The second project aimed at the construction of a solar farm (70 MWp which later grew to 83 MWp) at one of the company's postmining areas.

Origins and plans

Unlike all other major Polish energy companies, which are state-owned enterprises (SOE), ZE PAK is privately owned. This makes the company relatively independent from national policies and somewhat less pressured by strong coal mining trade unions interested in preserving the state's support for coal. Also, as a private company, ZE PAK arguably has a lower aversion to risk compared to SOEs, which often tend to adopt more cautious and shorter-term strategies. These characteristics supported a willingness to make investments in new technologies and allowed the company to have the leading role in developing the hydrogen ecosystem in Poland.

Another factor allowing ZE PAK to initiate its green transition was new financing opportunities, which started to appear in 2018, along with the creation of the Initiative for Coal Regions in transition. These developments helped to stimulate the company to conceptualise different projects in green sectors.

In 2019, ZE PAK prepared a preliminary project for hydrogen production based on the energy generated in its new biomass installation in Konin and other RES. The hydrogen produced by the company and distributed by its filling stations was to be used by public transport services in Konin and other Polish cities, as well as by the company's own hydrogen car fleet.[5]

In 2020, ZE PAK selected and signed a contract with a technology provider for an electrolyser and a filling station with mobile storage systems to be installed in Konin. In the same year ZE PAK also prepared a plan for the construction of a hydrogen bus prototype (Nesobus) and production factory, to be located in Świdnik, in the Lubelskie region).

In 2022, the company planned to construct six more hydrogen filling stations in Warszawa, Rybnik, Lublin, Wrocław, Gdańsk, and Gdynia. The plans also included purchasing trailers for hydrogen delivery to filling stations.

Despite a substantial delay in the installation of the Konin filling installation,[6] ZE PAK managed to develop a wide portfolio of hydrogen projects within 6 years. Problems with the delivery of hydrogen to the filling station in Konin, which was to begin operating in 2022, led to 2 years delay, but according to ZE PAK, it is expected to start operating in July 2024.7 Two of the six filling stations that ZE PAK was to build are already operational, and the other four are still under construction. Regarding Nesobus, the facility in Świdnik

4. Detailed descriptions of RES and hydrogen-related projects are available in the company's annual reports (2018-2024) at: https://ri.zepak.com.pl/pl/raporty/raporty-okresowe.html?y=2024. For earlier summary information in English see: https://www.zepak.com.pl/en/about-us/press-office/news/12534-green-hydrogen-in-zepak.html and https://climate.ec.europa.eu/system/files/2022-07/if_pf_2021_zepak_en.pdf.
5. In the following years, the company decided to open new solar and wind farm projects. However, due to instability of the energy supply none of them was linked with hydrogen production.
6. Two years delay was caused by a security incident in an installation of the company in another location; source: link
7. Source: link

is already built, and the first buses have been delivered to the clients – Polish cities which, decided to invest in a hydrogen fleet of public transport vehicles.

Although all ZE PAK's green investments have weighed on its financial situation, which could be detrimental to smaller companies. this has not prevented the company from testing the use of hydrogen cells for home energy supply, which is a potential new investment area.

Structure of collaboration

Creation of the hydrogen ecosystem was reinforced through ZE PAK's collaboration and relations with various stakeholders, regionally, nationally and at the EU-level.

Although the national government declared the net-zero target only for 2050, the regional authorities in Wielkopolska created their own regional strategy aiming at reaching this goal in 2040. Hydrogen technologies were also adopted as one of the region's key smart specialisations priorities. Through its advisory body, the Wielkopolska Hydrogen Platform, the region developed the concept for future hydrogen not only at the European level but also through organising economic missions and participation in different hydrogen-related fairs in the most advanced countries at the time, like Japan and Korea.

The Regional Development Agency, which is owned primarily by the Wielkopolski region and local governments of Konin and surrounding communities, is an active contributor to developing the hydrogen ecosystem. Tasked with supporting the restructuring of the regional economy and development of the SME sector, the Agency has been involved in collaboration with the World Bank, the Life project (Life after Coal), and the Powering Past Coal Alliance, to promote the region's ambitions to phase out coal and look for new growth engines such as hydrogen.

At the national level, ZE PAK used the support of the government in several areas. It participated in consultations on setting-up the national support programs and creating a favourable legal environment, including norms and standards for hydrogen. Interestingly, however, the Eastern Wielkopolska ecosystem remains independent from the government's hydrogen strategy that was adopted in 2020 but does not include Wielkopolska among the (at least) five hydrogen valleys to be created under the strategy.

At an EU level, the Initiative for Coal Regions in Transition, opened an international dialogue among the private, public, academic, and NGO stakeholders. Later, the creation of the Just Transition Mechanism, including the Just Transition Platform, offered the possibility to access substantial financial resources to support *inter alia* the development of new technologies in coal and carbon intensive regions.

Resources

ZE PAK is the main investor in the hydrogen projects in Eastern Wielkopolska and has made use of multiple public support programs to finance its projects. The EU's Innovation Fund is being used to finance investment in electrolysers at the green hydrogen production facility in Konin, which uses energy from ZE PAK's solar farms, and is a core element of the Eastern Wielkopolska's hydrogen ecosystem. Further, the company's projects related to hydrogen fuelling stations in 5 cities and the production of hydrogen buses were financed by the National Fund for Environment Protection and Water Management (NFOŚiGW). The Fund is responsible for managing the revenues from the EU ETS in Poland.

Key lessons

The development of the hydrogen ecosystem in Konin and, more specifically the activities on ZE PAK provide some important lessons that are summarised in this sub-section

Creating the hydrogen ecosystem

- **Development of the ecosystem can be pioneered by a large local company** using external technology providers. In the absence of local, technologically advanced SMEs, a local company acting as a technology integrator is an alternative option to access public financial support to start building an ecosystem. Increasing local content can be developed at a later stage, as the case of Nesobus shows, while creating opportunities for high quality jobs (even if quite limited in terms of the number) based on new skills.
- **Supports and collaboration of regional administrations are important**. The progressive energy transition agenda of regional and local public administrations (Wielkopolska Marshal Office and the city of Konin) has been important for encouraging investments in hydrogen. Also, the collaboration from government has been critical for securing funding or in ensuring necessary legislation. Even though initiatives of the national government, especially with a top-down approach regarding the creation of hydrogen valleys, has not been favourable to Wielkopolska this has been compensated by support at the regional and local level.

Communication

- **Separate communication on the hydrogen project from the phase-out of fossil fuels**. The topic of lignite phase-out was framed in the context of unfavourable conditions for fossil fuels in the EU and globally. The opposition of

the mining trade unions has been handled partly at the country level by the Social Contract, which offered several labour market instruments for lignite mining and power plant workers. In addition, ZE PAK assigned an allowance per worker for the re-skilling and replacement services. In comparison, the topic of hydrogen was presented as part of the debate on the future of the region and ZE PAK's role within it. Communications towards the local population and public authorities focussed on hydrogen technologies as part of the solution to keep high-quality jobs and revenues for local public authorities, and thereby providing an incentive for younger persons to remain in the region.

Financing

- **Mobilise multiple sources of finance and maintain good collaborate with managing authorities**. EU funds channelled through operational programmes are currently one of the most important instruments for financing key elements of a future hydrogen ecosystem, and can help to reduce the risk of investments. Financial support can be delivered through operational programs, the Just Transition Mechanism with all its three pillars, and the distribution of revenues from the EU ETS (Emissions Trading Scheme). As national authorities responsible for managing these funds can have significant influence on the distribution of European Funds, maintaining close contacts and cooperation the relevant managing authorities is important.

Leadership

- **Leadership of the ecosystem development can bring positive returns**. Even though leading a project can bring an additional administrative burden innovators and even if innovators may fail to fully reap the economic benefits of their innovations, there is also an economic rent for taking up a leadership role. By itself, leadership can bring valuable positive public relations benefits, but it also attracts the attention of different stakeholders with which new ventures can be created.

Recommendations to Stara Zagora

Context

This section outlines of the general context for the development of a hydrogen valley in Stara Zagora Region, highlighting relevant activities and circumstances.

Economic context of Stara Zagora

The economy of Stara Zagora Region has traditionally been dominated by coal mining and electricity production in the region. Other notable economic activities are the production of military equipment, metal processing, and agriculture and food processing. Coal mining and associated electricity production will be hit hard by the shift to a sustainable energy system to meet obligations under the Paris Climate Agreement and the foreseen cessation of coal-based electricity production by 2038. This will result in ending of coal (lignite) mining activities in the region and the closure of thermal power plants in the Maritza East Energy Complex. These activities are a pillar of the local economy, with the Bulgarian Ministry of Energy estimating[8] that 12.000 jobs in the Maritza East Energy Complex will be affected and an additional 15.000 jobs ii\n the wider economy likely to be affected by 2038. If dependent family members are included, over 100.000 people or 30% of the region's population could be affected. Moreover, the gross value added (GVA) of mining and energy activities in Stare Zagora amount up to 15% of the national GDP. The economic interests of the transition to a sustainable energy system cannot be understated.

Just Transition Plan

The Territorial Just Transition Plan (TJTP) of Stara Zagora identifies three pillars to transform the local economy to a climate neutral and long-term sustainable future.

- Industry for sustainable energy solution;
- Social and employment support;
- Diversification of the local economy.

As part of the first pillar, the TJTF identifies development of a hydrogen valley in Stara Zagora Region as a priority for economic development and diversification. Such a development is supported by several regional assets, notably a stable and well-developed power grid, high technical skill of the local labour force, high solar activity and a well developed transport and education infrastructure.

Stara Zagora Hydrogen Valley project

Stara Zagora's hydrogen valley, dubbed ZAHYR (ZAgora sustainable HYdrogen Region), is the first nucleus around which further hydrogen related activities can be developed in the region. This project is in a preparatory phase, with a core project team consisting of employees of the Stara Zagora Regional Economic Development Agency, Trakia University and the European Digital Innovation Hub Zagore. This team is taking the lead in finding (private) partners that can join the consortium and funding for the projects. ZAHYR is designed with two modules connected to a single 20 MWp PV park, which is poised to be installed on a former landfill:

- The first module is located around Stara Zagora city. A 2 MW electrolyser provides the hydrogen for ten busses and two trucks, as well as for a 1 MW fuel cell that provides electricity for street lighting.
- The second module is located at the Maritza East Energy Complex. Here a 3 MW electrolyser generates hydrogen for a small fleet of lightweight vehicles. Additionally, the hydrogen will be mixed with natural gas to power a gas turbine to generate electricity for the 'general power grid'.

Funding

Several European funds are – actually or potentially – available to support development of the hydrogen valley:

- The Stara Zagora region is a region eligible under the Just Transition Mechanism (JTM). The development of a hydrogen valley is a key component for the transition away from a coal-based energy system. The establishment of a hydrogen value chain, PV-park for electrolysers, hydrogen storage and support schemes for the utilisation of green hydrogen are identified as investment priorities under the Territorial Just Transition Plan (TJTP) for Stara Zagora.
- Funds may be available from the European Union's the Recovery and Resilience Facility, from which the Bulgarian national government has earmarked significant parts of the available funds for development of new energy systems and green hydrogen pilot projects.
- In 2023 it was announced that ZAHYR had been designated as a small-scale European Hydrogen Valley that would be supported by the Clean Hydrogen Partnership. This made available a grant of nearly EUR 8 million euro through RePowerEU under the Horizon Europe programme.
- A consortium including the Stara Zagora Regional Economic Development Agency has received a grant from the European Interreg programme to support the GH2M project, which aims to accelerate the integration of green hydrogen in the transportation sector.

8. Ministry of Energy of Bulgaria (2023). Territorial Just Transition Plans. Available at: https://www.me.government.bg/uploads/manager/source/VOP/TP/TPEN/JTPStZagora_en_02.08.23.pdf

Proposal and recommendations for a roadmap for hydrogen valley development

Based on the case studies of HEAVENN and Wielkopolska, six phases in the development of a hydrogen valley in Stara Zagora can be identified, which are outlined below. These phases do not necessarily follow each other in a linear fashion but may overlap or run parallel. Where this is the case, it is indicated in the description of the phase(s).

Phase 1: Motivated core team

The first phase of hydrogen valley development is to set up a core project team, which will be the main body driving initial development. This team can be small in the beginning but can be expanded as and when required. It should have excellent contacts in the local business community, local research and development organisations, and both local and national government. The team should possess knowledge of the hydrogen value chain and business development. The basic components of a core team already exist in Stara Zagora Region, through the existing cooperation between the Stara Zagora Regional Economic Development Agency, Trakia University, and the European Digital Innovation Hub "Zagore".

Phase 2: Laying the foundations

Hydrogen is a novel technology that is not fully understood by many people. Additionally, many parties in the region have vested interest in the continuation of the status quo of coal-based electricity production (e.g., coal mining sector and power plant operators, their networks of suppliers and sub-contractors, workers in these sectors and their representative organisations). To overcome resistance and build acceptance of hydrogen, a clear and concise narrative of the need for developing a hydrogen valley and its benefits for affected stakeholders and the wider community is required.

Creating a narrative is not an easy task since it needs to fulfil two roles. First, it needs to ease people's fears of losing what is familiar, such as their jobs and their lifestyle. Second, it needs to inspire action to work towards a largely unknown and uncertain future. People need to not only come to view hydrogen as a 'natural' part of their environment (in the same way as coal or natural gas are today, or other renewable energy sources such as solar and wind power are for tomorrow) but, also, be inspired by the opportunities that hydrogen can bring.

Equally, the narrative needs to remain realistic and capable of being conveyed simply and succinctly. And it needs to balance rational and emotional arguments. Many of the core building blocks for the narrative have already been developed for Stara Zagora. The next step would be for the core project team to craft these narrative building blocks into an attractive story. In this regard, two main sub-groups of the wider audience can be differentiated with each requiring a tailored approach:

- **Potential partners in the consortium**, for whom the narrative needs to be built around organisational and economic arguments. Especially for private business partners, they need to be convinced that potential economic/financial risks of becoming partners are mitigated. Regular contact and an informal cooperation are likely to be effective means of communication.
- **The general public**, for whom the narrative needs to be concise and tailored to their doubts and needs. They are less likely to be convinced by economic arguments, but rather by offering them the possibility of stability and security. Effective means of communication are the use of mass media and communication campaigns. Additionally, it can be helpful to demonstrate low-key practical hydrogen applications in their day to day lives. If people see a hydrogen powered car every day, a hydrogen-based economy will seem less abstract and more relevant to them.

Phase 2 is a continuous element of the hydrogen valley development, as creating acceptance and support for hydrogen is an ongoing process that will have to continue after creation of the hydrogen valley.

Phase 3: Preparation of the consortium

Having set the foundations and built local support and acceptance for hydrogen, formation of a consortium of partners to develop and implement the hydrogen valley can begin. The most obvious way to go is to build a consortium based on a partnership of public and private actors. This is especially so if the hydrogen valley project intends to leverage financial support from European Funds, many of which will cover only part of project costs and will therefore necessitate private investments to cover the remainder. Moreover, securing private investment from (local) businesses will tie development of the hydrogen valley into the local economy. While the involvement of public entities is more likely to secure ongoing support from the local and national governments.

The composition of the consortium will depend on the final design of the hydrogen valley and the scope and depth of its activity. However, to cover all the main ecosystem elements necessary to complete the valley, the partners will need to at least encompass the following elements (roles):

- Production of hydrogen
- Transportation of hydrogen

- Storage of hydrogen
- Consumer/user of hydrogen
- Project leadership and overall administrative functions.

Also, as indicated above, the involvement of government (i.e., regional or national public administrations) as a consortium partner can be important, as is also the case for organisations able to provide technology research, development and innovation capabilities.

Each of the roles needs to be covered by at least one of the partners but this does not preclude individual partners fulfilling multiple roles, although it is preferrable that a single partner does not have too dominant a role in the consortium. Preferably, multiple partners can be included for each role, as this means that there is a 'back-up' if a partner withdraws or is unable to fulfil their anticipated role(s), while also leaving the possibility to develop several parallel and intersecting value chains.

For Stara Zagora, there are some obvious partner candidates, such as the Regional Economic Development Agency and Trakia University. If lignite mine and power plant operators, who are key players in the transformation process and have considerable weight in the local economy, can be convinced to join the consortium it would send out an important signal to stakeholders and communities in the region that hydrogen offers a viable alternative to fossil fuels.

A relevant consideration for formation and operation of consortium concerns the degree of centralised control. HEAVENN has relatively little centralised control and in many ways can be considered as a collection of a few dozen individual projects. This structure works in the Dutch cultural setting, but it would be for the core project team to decide whether this structure is also a good fit in the Bulgarian context.

Another relevant consideration is the extent to which the government is willing to financially support the hydrogen valley, especially in the early stage of the project. Government support may be key for encouraging private parties to join; a firm commitment from the government, including their participation as partners, can help when negotiating with private parties to convince them to join the consortium.

Phase 4: Designing the valley

Dialogue with potential project partners during preparation of the consortium serves to help identify opportunities for the hydrogen valley's development, based on their interests, capacities, and assessment of the (local) conditions and attributes. This dialogue sets the scene for defining a first design of the hydrogen valley, which should not only include scoping the value chain, but also consider financing aspects (e.g., availability of public and private funds for investments and operations), organisational structure, and respective roles and responsibilities.

The design of the valley should secure as much support as possible from the project partners. This likely requires many revisions to the design and, accordingly, a lot of effort from the core project team to build 'buy-in' and consensus among the project partners. However, one of the lessons from HEAVENN is that it is worthwhile to have a detailed design of the valley before launching the project. Not only does it provide clarity to each partner about their role and responsibilities, but it also makes it easier to get grant(s) awarded. In principle, the design of the hydrogen value chain should at least cover the following elements:

- The proposed value chain / ecosystem (i.e., production, transportation, storage and consumption/use of hydrogen)
- Awareness and demonstration (e.g., recognisable application of hydrogen in the public space)
- Implementation timeline
- Plans for scaling up the chain, both in volume, parties involved and duplicate roles.

Phase 5: Implementing the project

Implementation of the project will require a mix of capabilities, including capabilities for business development and for undertaking R&D and innovation activities. If the right mix is unavailable, it will be difficult to advance the project, and there may be a need for more experienced partners to support less experienced ones. There should also be an acceptance among the partners – including those organisations that provide public financial support –that there will inevitably be setbacks. Partners encountering difficulties should be supported, and treated leniently if things fail or if project goals are not fully accomplished. Looking at the ZAHYR project, which is designed as a small-scale demonstration valley, the attitude of all parties involved with the project should reflect a realistic evaluation of the inherent risks of the project and the capabilities on the partners, individually and collectively.

With the setting-up and implementation of multiple project elements, monitoring and coordination will be important to ensure that progress on each element is aligned. This will require regular updates from the partners and exchange of information between them. At the same time, the core project team should try to minimise the burden on partners so that fulfilling administrative tasks with does not overly impede actual project implementation.

Phase 6: Post-project follow-up

Planning for the post-project phase should begin well before the project is completed. For a hydrogen valley two axes for post-project development come to the fore. First, scaling-up of the valley in terms of increased production and consumption/use of hydrogen. Secondly, the breadth of the valley should be widened, bringing in more organisations so that there is increasing duplication of roles within the hydrogen eco-system, so that there are multiple instances of production, storage, transportation and consumption. This can go hand-in-hand with widening the variety of hydrogen applications within the valley, for example extending the use of hydrogen from mobility applications to its use in industrial processes. Consideration should also be given to whether the existing core project team has the right set of skills and capacity to take forward the future development of the hydrogen valley or if new partners need to be brought in, either to complement the existing team or to take over the leadership role.

Risk Assessment

This section provides an initial assessment of the main risks for development of a hydrogen valley in the Bulgarian context and possible actions that could be taken to mitigate these risks.

Local support

Risk

One of the major risks for development of hydrogen valley is a lack of local support and, in the extreme, actual resistance to the project. Particularly, in an economy that is heavily dependent on coal (lignite), hydrogen-related actions could be viewed as a threat to the *status quo* rather than opportunity for economic development and diversification. Also, if the socio-economic case for hydrogen (e.g., the business case, employment opportunities, environmental benefits) is not clearly articulated, there is a risk that the local population and business community will view it as a 'novelty' that has been foisted on them from outside. Lack of local support risks seriously hampering development of hydrogen in the region.

Mitigation

There are two main dimensions to mitigation of a lack of local support. The first addresses the interests of the business community and, especially, the coal sector (i.e., mining, power plants, and their supply chains). In as far as possible, involvement of entities from the coal sectors as project partners should be encouraged, as it would both imply that these major players in the local economy are invested in the success of the hydrogen valley, which would also send a strong signal to the local population. On the one hand, if governments strictly adhere to their policy of phasing-out coal, this will necessitate that businesses look for alternative energy sources. On the other, EU, national and regional policies and availability of funding for projects increases the attractiveness of pursuing hydrogen as a future development opportunity.

The second dimension targets the local population, who may have little knowledge or understanding of hydrogen and may be apprehensive about what pursuing the development of hydrogen could mean for them. Accordingly, communication and awareness raising activities will be important, and will need to be implemented by the project core team (e.g., the Regional Economic Development Agency and the University) but, also, may involve identifying 'ambassadors' for hydrogen that are influential and respected by the community and can effectively propagate positive messages around hydrogen. As noted earlier, developing a narrative on hydrogen will be necessary, and this can be facilitated by developing early-stage application of hydrogen that intersect with peoples' day-to-day lives and can be used to raise hydrogen's visibility within the population.

Additionally, the core team can reach out to other European hydrogen valleys that may be able to provide valuable insights on building support for hydrogen projects and targeted narratives for different stakeholder groups.

Political support

Risk

Instability in the political environment, for example due to national or regional elections, can make it difficult to be sure about policy frameworks, goals and support measures for hydrogen. In turn, this can make it difficult to set project goals and priorities and then work towards them.

Mitigation

Although political uncertainty cannot be removed, the core project team can take steps to engage as widely as possible with government representatives and public administrations to build political-level support for the hydrogen valley project. Activities to propagate political-level support can be reinforced if, for example, elections lead to a change of the national or regional administration. Additionally, nurturing local support (see above) for the hydrogen valley project can raise awareness and public support at the national level, with the possibility of encouraging government actors to adopt a positive policy position towards hydrogen.

Private sector financing

Risk

Although public sector financial support is available to support hydrogen development (e.g., EU Recovery and Resilience Facility, and Horizon Europe programme), private investment will still be necessary. To date, attracting private sector partners for the development of hydrogen in the Stara Zagora Region has proved difficult, and a few partners have even left the consortium behind the hydrogen valley development.

Mitigation

Enterprises may naturally be hesitant about the financial commitment and risks associated with participating in the hydrogen valley project. Providing clarity over financial arrangements and safeguards will need to be addressed and will need to be discussed as part of the negotiations with companies when seeking their participation. Local and national public administrations have a role to play that goes beyond direct financial support, to include fiscal and administrative arrangements covering investments and operating costs related to the project. This means that the local and national government should be moved to help these companies. The situation can be likened to providing support for business start-ups and help for product development and scaling-up production. Clearly, the more supportive these frameworks can be made, then the lower will be the risks for partners making investments. In addition, the core project partners – notably in the case of Stara Zagora, the Regional Economic Development Agency – can play an important role as a 'middleman' between project partners from the local business community and the relevant governmental administrations.

Scaling-up the project

The ZAHYR valley is designed on a demonstration scale. Ultimately, for the hydrogen valley to be self-sustaining in the longer run it will need to be scaled-up to a commercially viable scale. If this does not happen, then the valley will not become anchored in the local economy and unlikely to survive from the moment that public support comes to an end or is withdrawn. The issue of how to create conditions for the long-term sustainability of the hydrogen valley is considered in the next section.

Long-term sustainability plan

The goal of the long-term sustainability plan is to make sure that the hydrogen valley will continue to function and grow after the initial demonstration project phase has been completed. To achieve this, the activities within the valley will need to become commercially viable (i.e. sufficiently profitable that they generate an adequate return on investment) without public subsidies. The project will also need to garner sufficient support from the local population, political bodies, and important economic actors to develop their activities and scale of operations (the so-called 'license to operate'). Taking actions at the end of the project to achieve this is unlikely to be adequate. Ideally, key actions should be incorporated in the design of the project from the outset.

Regarding financial viability, there should be a clear rationale for providing temporary (initial) financial and other support for creation of the hydrogen valley, for example:

- After initial investments have been made, it will be possible to develop profitable industrial operations.
- As the project is scaled-up, and as new technological development and innovations are introduced, the costs of production and operations can be reduced sufficiently to make hydrogen a competitive alternative to other energy sources.
- Development of the valley requires coordination of investments to simultaneously develop different parts of the value chain that cannot be achieved without 'third-party' intervention.

Regarding support from the population, politics and business, it needs to be demonstrated that a hydrogen-based development model is viable and can deliver economic, social and environmental outcomes that improve on (or at least are equally beneficial as) the current development model in various areas:

- The new model should provide high-quality and well-remunerated job opportunities. And, in addition, these jobs should match with those in the workforce – especially those most affected by transition – or, if not, training and education programs will be implemented to develop the necessary skills.
- The new model should have a beneficial impact on the natural environment or, at least, should not result in a degradation of the environment.
- The new model should create opportunities beyond the enterprises and sectors directly impacted by coal (lignite) phase out, such as suppliers and sub-contractors of mining and power plant operations. To this end, support programmes should be developed to help such enterprises to adapt their business models to the new hydrogen-based development model, which may require considerable time and resources.
- The new model should be part of a larger vision for the future of the region as a whole. Every region requires a mix of economic activities that fit together to make the region economically successful. Therefore, the new model cannot be

developed in isolation, but should be tested for compatibility with other priority areas for economic development and diversification.

When the design phase is completed, the progress of the implementation of long-term sustainability actions should be monitored. This will require definition of key performance indicators, with clear (and if possible quantitative) target values, and predefined remediation actions if these targets are not met. The next sub-section discusses the monitoring framework in more detail.

Monitoring and evaluation framework

A general evaluation framework to gauge the progress and success of each phase of implementation of the project is illustrated in Figure 3. The framework consists of four elements:

- **Input**: all required resources for each phase, usually defined in terms of human (e.g., person hours) and financial resources.
- **Activities**: all activities executed by all parties in each phase;
- **Outputs**: all tangible results of the activities, such as documents, agreements, physical equipment etc.
- **Impact**: The effects of the outputs, usually defined on a more general level and applied to the overarching goal (i.e., contribution to development of a hydrogen valley.

When evaluating the success of each phase, there are at least two important metrics to consider:

- **Efficiency**: How efficiently resources have been used, which requires evaluating the comparison between outputs achieved to resources used. The key question is whether the resources and outputs are balanced, or are there alternative approaches for using resources that could achieve equivalent or better output levels?
- **Effectiveness**: How well are the outputs achieving the goals of the activities? To determine this, the outputs are compared with the impact they have. Do all efforts contribute to the goal? Are there other outputs that might contribute more to these goals?

The general evaluation framework can be applied to the roadmap for the development of a hydrogen valley in Stara Zagora, yielding a structured framework for monitoring the success of each phase, as illustrated in Figure 4.

FIGURE 3: GENERAL EVALUATION FRAMEWORK

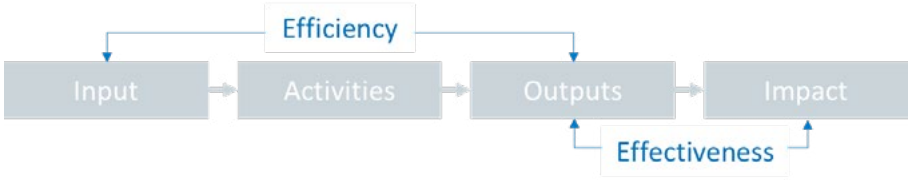
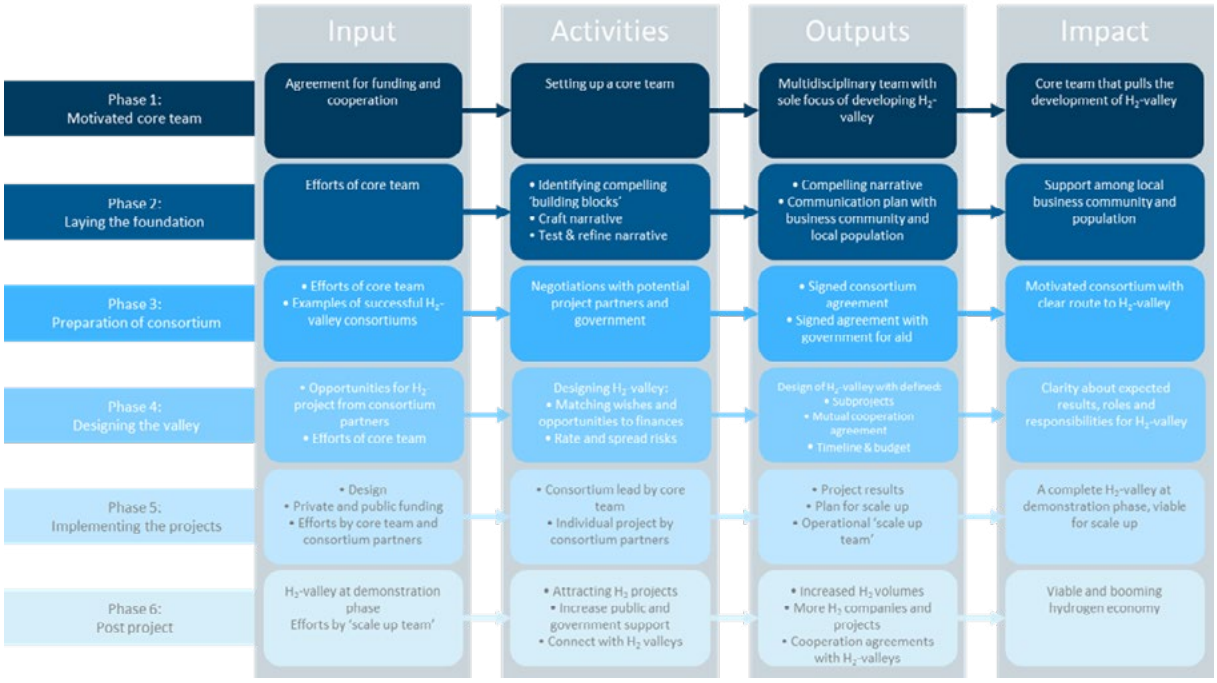


FIGURE 4: EVALUATION FRAMEWORK FOR THE DEVELOPMENT OF A HYDROGEN VALLEY IN STARA ZAGORA



The evaluation framework should be developed in greater detail for each phase of development of the hydrogen valley demonstration project, based on available information about the local context, to monitor the progress of the development of the valley. Additionally, a structured monitoring process needs to be developed, which entails determining appropriate indicators for the inputs, activities, outputs and impact in each phase, with a procedure for how to measure it. This corresponding monitoring information can then be used to evaluate each phase after it is finished and, also, to adjust course when necessary to optimise outcomes.

Annex – persons of interest

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Initiative for coal regions in transition

The Initiative for coal regions in transition is led by the European Commission.

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