ACT Project Number:
271498

Project name:
ELEGANCY

Project full title:
Enabling a Low-Carbon Economy via Hydrogen and CCS

ERA-Net ACT project

Starting date: 2017-08-31
Duration: 36 months

D5.5.2
German Case Study: Final Design and First Results

Date: 2019-02-28

Organization name of lead participant for this deliverable:
Ruhr University Bochum

ACT ELEGANCY, Project No 271498, has received funding from DETEC (CH), BMWi (DE), RVO (NL), Gassnova (NO), BEIS (UK), Gassco, Equinor and Total, and is cofunded by the European Commission under the Horizon 2020 programme, ACT Grant Agreement No 691712.		
Dissemination Level		
PU	Public	x
CO	Confidential, only for members of the consortium (including the Commission Services)	

Deliverable number:	D5.5.2
Deliverable title:	German Case Study: Final Design and First Results
Work package:	WP 5 Case Studies
Lead participant:	RUB

Authors		
Name	**Organisation**	**E-mail**
Daniel Benrath*	RUB	Daniel.Benrath@rub.de
Stefan Flamme	RUB	Stefan.Flamme@rub.de
Sabrina Glanz	RUB	Sabrina.Glanz@rub.de
Franziska M. Hoffart	RUB	Franziska.Hoffart@rub.de

Keywords

H_2-CCS chain, gas infrastructure, legal landscape, KSpG, EnWG, CCS, CCT, CO_2 partial pressure, hydrogen production, hydrogen industry, hydrogen admixture, social acceptance, stakeholder analysis

Abstract

By combining hydrogen and carbon, capture and storage (CCS) technologies, the project ELEGANCY aims to accelerate the decarbonisation of Europe's energy system. Within the German case study, different infrastructure options in regard to an integrated H_2-CCS chain are analysed. This includes technical, macroeconomic, legal and sociological aspects. The paper aims, first, at defining the final design and methodology of the German case study and, second, at presenting intermediate results of each discipline's contributions. The approach for the final design consists of five steps: For a base case analysis, the results of the individual disciplines (step 1) are combined (step 2), which is used to determine best case options (step 3). In the best case analysis, the contributions of the individual disciplines (step 4) are combined to develop feasible concepts and recommendations (step 5). As intermediate discipline specific results, relevant data for the technical analysis, such as the CO_2 partial pressure of the point sources and the actual capacity of the hydrogen production facilities, is shown. Especially, industrial H_2 can be replaced as – by now – 70% of it is produced with CH_4 reforming. Additionally, the technical methodology was further refined. The macroeconomic scenario analysis resulted in six raw scenarios. These scenarios vary in the level of overall transformation which is mainly driven by the interaction between the stakeholder groups. As intermediate results, the system image, key factors and the importance of stakeholder dynamics are discussed. It can be concluded that the overall level of transformation largely determines the feasibility of the infrastructure options. For the legal contribution, the applicable law for different kinds of pipelines is mapped and discussed in respect of relevant areas of law. Despite parallels, the different regimes partly refer to different focuses (waste, energy, safety) and show marked differences in the regulatory structure and quality. Especially, the law for energy H_2 pipelines is shaped by intense legal uncertainty. The sociological analysis presents first results from the explorative stakeholder interviews. These indicate controversial as well as consensual perceptions of the options from the stakeholders' perspective. The assessments range from rejection of an H_2-CCS chain to deeming it absolutely necessary. Risk perception, infrastructural consequences and compatibility with renewable energies have been identified as key factors for social acceptance.

TABLE OF CONTENTS

Page

1 INTRODUCTION

ELEGANCY aims to accelerate the decarbonisation of Europe's energy system by combining carbon capture and storage (CCS) and H_2 with a full chain H_2-CCS infrastructure linking together Norway, the Netherlands, Switzerland, the UK and Germany. The German case study aims at enabling the accelerated (partial) decarbonisation of the German infrastructure through H2-CCS chains, examined from a technological, macroeconomic, legal and sociological perspective.

In the first deliverable (D5.5.1), preliminary assessments of options for a decarbonised gas infrastructure were elaborated. The purpose of the present deliverable (D5.5.2) is to outline the final design and methodology of the German case study and to present first results. The report thus serves as a basis for the further proceeding of the case study and determines the common interface of the four disciplines.

In a first step, the final design and methodology is defined by describing the interdisciplinary contributions and cooperation in the case study and by specifying the common framework of the examinations. In a second step, for each discipline, the approach and intermediate results with regard to an evaluation of the options are presented.

2 FINAL DESIGN

The goal of the German case study is to find and examine a feasible concept for a way to decarbonise the German infrastructure through H_2-CCS chains. The case study is aimed at accelerating the decarbonisation in a bridging period. For this, different options are tested in regard to essential aspects of feasibility, especially potentials, costs and risks.
Three base options for developing the infrastructure are taken into account as a starting point. They cover a wide range of possible approaches to integrate the relevant sectors, especially industry and energy, into H_2-CCS chains on a conceptual level. In **option 1**, carbon dioxide will be captured at large point sources and transported to the Netherlands for off-shore storage. This option requires no changes in the existing natural gas infrastructure and is insofar closest to the status quo, but it requires the establishment of completely network structures in regard to CO_2. In **option 2**, H_2, which is largely produced from natural gas using CCS in Norway, is admixed into the existing natural gas grid. This option demands broad adjustments of the natural gas grid. In **option 3**, H_2, which is produced as in option 2, is transported in a separate grid to the end-users. This option leaves most of the natural gas grid untouched while establishing a completely new concurrent gas infrastructure.

2.1 Approach

At the core of approach of the German case study, the different options are analysed from different disciplinary perspectives.

Table 2.1: Overview disciplinary contributions.

Discipline	Focus	Methodology
Technical contribution	CO_2 reduction potential and abatement costs	GIS-based models for the three base options, consisting of future framework conditions and specific data on the H_2/CO_2 sites under consideration are developed. The infrastructure is planned based on the routing of the natural gas network.
Macroeconomic contribution	Conditions that foster or hinder the implementation of a modified gas infrastructure	By using a complexity economic approach, the infrastructure options are assessed in terms of economic and political feasibility. For this purpose, we conduct an economic-centred stakeholder analysis, that is based on qualitative, descriptive scenarios.
Legal contribution	Legal costs, risks and constraints; legal framework for supporting actions	The existing law in regard to major issues is analysed. Additionally, the systematic lines, potentials and constraints for further legal development are examined.
Sociological contribution	Chances and risks for public acceptance of the options and its components in the German population	The analysis of social acceptance is based on an empirical study. A mixed-methods-design is applied: Explorative interviews are conducted to capture and understand the stakeholders' perspectives; representative data of public acceptance in the German population is gathered by a quantitative online survey.

Taking into account different scenarios, these perspectives are combined into a common analysis of the base options and the further exploration of a feasible concept.

1. In a first step, the researchers of the different disciplines explore and analyse the costs, risks and barriers as well as the potentials and benefits attached to the different base options

from their respective perspective with their respective methodology. Where relevant, the different disciplines exchange and the tools provided by WP3 and WP4 are considered.
2. The results of the disciplinary analyses will be combined into a common analysis and assessment of the base options. This assessment will consider the framework provided by WP 3.
3. Based on the common analysis of the base options, best case options which show to be most feasible in relation to each other will be determined. The best case options may go beyond the base options and integrate detailed findings of the analysis. Thus, it is possible that the best case options are more differentiated and combine aspects of different base options.
4. The best case options will be further analysed from the different disciplinary perspectives to gain a deeper understanding of the feasibility, the conditions of success, the risks, the hurdles and the potentials of the best case options.
5. Based on the analyses of the best case options and their combination, potential concepts to develop the German infrastructure towards decarbonisation within H_2-CCS chains will be assessed and, if possible, feasible concepts will be presented. These concepts will contain recommendations to benefit from the potentials, mitigate risks and remove hurdles and address relevant constraints.

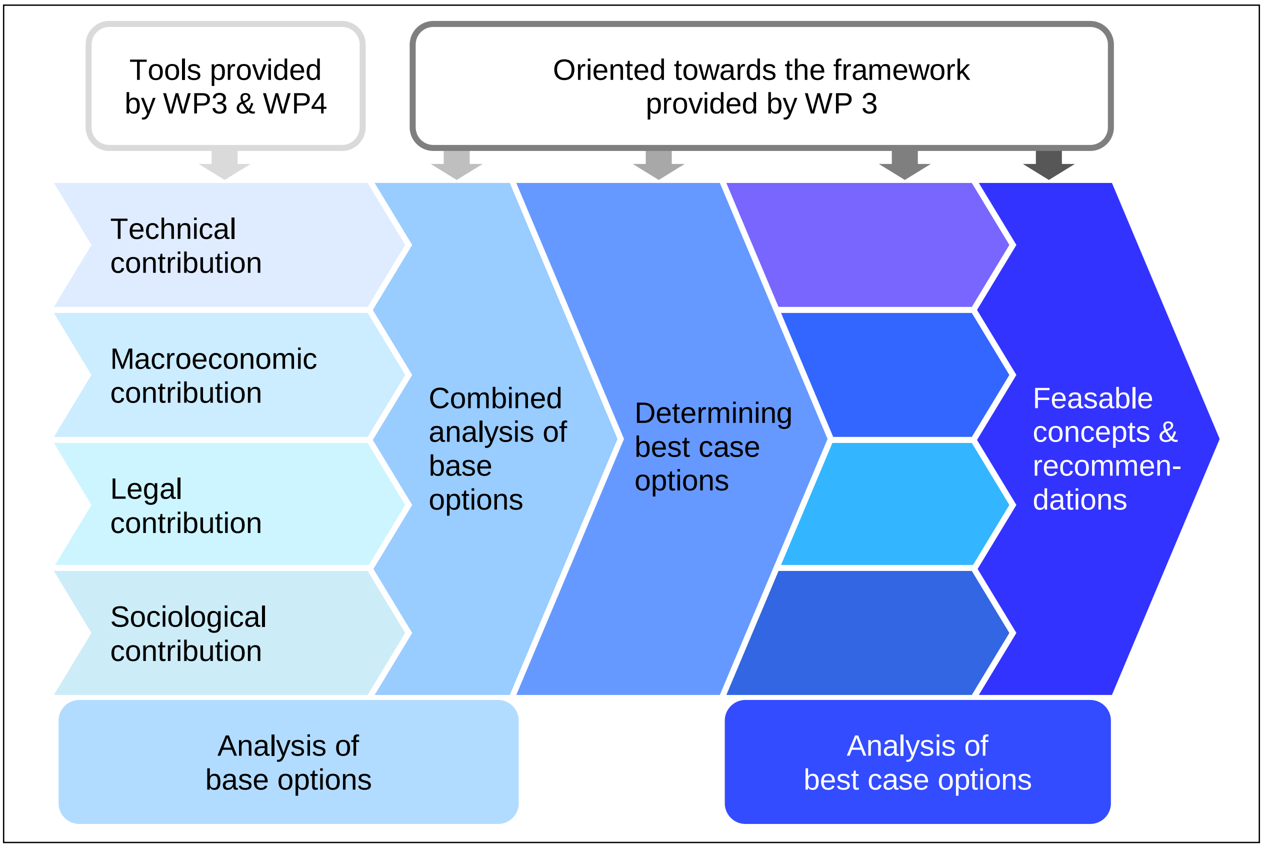

Figure 2.1: Procedure of the final design of the German case study.

2.2 Focus and Scenarios

A common framework in regard to the focus and scenarios align the interdisciplinary perspectives and the further research and analysis.

The examinations will be focused on 2035. This open focus describes a bridging period towards an extensive decarbonisation. The timeframe allows to take up the existing economy for extrapolations and gives enough space to plan and implement substantial changes in the infrastructure, without pre-empting the unclear further developments in regard to economy, technology, climate and political conditions. Furthermore, the focus on 2035 links to the results of D5.1.1 in regard to the potentials of the H_2 markets [BHA18]. Beyond this focus, the future development towards a significantly reduced role of fossil natural gas as an energy carrier in the gas grids will be considered to assess the benefits and drawbacks of the different options.
Other aspects of the common framework concern the different base options:

- For **option 1**, different scenarios in respect of carbon dioxide emitters are considered: Next to the base scenarios using the current industrial structure with or without coal power plants, it will be examined, in how far other scenarios are relevant for assessing the options. For this option, carbon dioxide will generally be transported via pipelines.
- For **option 2**, a general increase of the share of H_2 in the natural gas network will be examined. Most of the H_2 is imported from Norway, supplemented by local input of “green” hydrogen. Although differences in the regional distribution of H_2 depending on sources will occur and the introduction of separated networks with different shares of H_2 is not to be ruled out, a general increase taking into account regional maximums is an appropriate conceptual simplification to cover most relevant aspects of this option. For the analysis, technical changes in the existing transmission and distribution infrastructure as well as necessary changes for natural gas customers are examined. It is part of the further research, which shares are reasonable in regard to the necessary adaptions, aiming at rather high shares.
- For **option 3**, a basic transport network to connect major suppliers, especially imports from Norway, and major customers of H_2 is considered. This approach does not envisage an extensive network, but it is conceptually expandable and thus flexible. A clear focus for option 3 rests on the transmission level, but the analysis is open for aspects of the distribution level as well. This simplification is appropriate, as the most relevant challenges for shifting gas supply on the distribution level go well beyond the transport infrastructure anyway [SAD18] while separate analyses of H_2 distribution networks can easily connect to results in regard to the transmission network. The H_2 transmission network is based on existing natural gas pipelines, which have to be adjusted and supplemented. Next to the projected consumption of H_2, several potential additional usages, including substitutions of natural gas applications, will be looked at and examined for relevance.

If limits to the capacity of acceptance of carbon dioxide by the Netherlands or of the supply of H_2 by Norway are considered as relevant, will be determined during the research, taking into account the feedback provided by the Dutch and the Norwegian case study.

2.3 References

[BHA18] BHARDWAJ, R.; DE KLER, R.; BAUER, C. ET AL.: *Regional overview of requirements and potentials of H2*. – URL: https://www.sintef.no/globalassets/project/elegancy/deliverables/elegancy_d5.1.1_regional-overview-h2-market.pdf. 2018.

[SAD18] SADLER, D.; SOLGAARD ANDERSON, H.; SPERRINK, S. ET AL.: *H21 North of England. H21 NoE Report/2018*. – URL: https://northerngasnetworks.co.uk/h21-noe/H21-NoE-23Nov18-v1.0.pdf. 2018.

3 TECHNICAL METHODOLOGY AND RESULTS

The technical considerations in the German case study focus on the technical and infrastructural feasibility of the different options, starting with prioritisation of the sites to be investigated. The GIS system (geographic information system) QGIS is used to model the infrastructure and the necessary framework conditions, such as the gas infrastructure, future energy demands and nature and water reserves. Finally, the CO_2 reduction potential and the abatement costs for the options are determined.

The following describes the methodology and first results of the technical model. Some issues are still to be decided upon, i.a. because of missing data. Whether the chain tool developed by WP4 can and will be used in the technical considerations must be evaluated after the first version of the tool has been distributed.

3.1 Option 1 – Carbon Capture and Transport

The first option is to collect CO_2 from large point sources in Germany and to transport it to offshore storage sites in the Netherlands. The preferred way of transport is a pipeline system that shall follow the routing of the natural gas grid. It is still to be evaluated whether using trucks as a means of short-range-transport proves reasonable. The originally considered 397 CO_2 point sources come from the E-PRTR database and use data from the year 2015. Based on this data, the point sources are selected by the amounts of CO_2 (focus on the 100 biggest point sources), partial pressure in flue gas (medium to high) and proximity to the natural gas grid (<5km). The 100 biggest point sources range between 8.9% and 0.23% of the total listed emissions. Over 70% of these sources originate from power generation, 9.4% from the steel and iron industry and 5.5% from the production of refined petroleum products. Due to the targeted high partial pressures in the flue gas, some sources with smaller amounts than the biggest 100 point sources are also included in further considerations. The process of choice for the capture process depends on the partial pressure of CO_2 in the flue gas. Post combustion capture (post-cc) with chemical scrubbing will be used for low and medium concentrations, for high concentrations post-cc with physical scrubbing will be taken into account. Table 3.1 shows the assumed concentrations for the considered types of CO_2 point sources.

Table 3.1: CO_2 concentrations in flue gas for the considered point sources [GOE15; IPC05; VDA16; FNR14].

Sector	Source	Reference CO_2 concentration (vol.) in flue gas	Pressure flue gas / partial pressure CO_2 [MPa]	Classification
Energy	Hard coal	15%	0.1 / 0.015	Medium
	Lignite	16%	0.1 / 0.016	Medium
	Mineral oil	15%	0.1 / 0.015	Medium
	Coke gas	9% (see also: Steel)	0.1 / 0.009	Low
	Gas turbine	4,6%	0.1 / 0.0046	Low
	Gas (heating)	8,5%	0.1 / 0.0085	Low
Industry				
Steel	Blast-furnace gas	30%	0.1 / 0.03	High
	Coke oven gas	9%	0.1 / 0.009	Low
	Converter gas	35%	0.1 / 0.031	High

Cement	Cyclone economiser	14-35%	0.1 / 0.014-0.035	High
	Grate economiser	20-29%	0.1 / 0.02-0.029	High
Petrochemical	Oil refinery and heaters	8%	0.1 / 0.008	Low
Chemical	Ammonia (process)	100%	-	Very High
	Ethylene oxide	100%	-	Very High
	Ammonia (fuel)	8%	2.8 / 0,5	Low
	Ethylene (process)	8%	2.5 / 0.2	Low
	Hydrogen production	15-20%	2.2-2.7 / 0.3-0.5	Medium
	Methanol Production	10%	2.7 / 0.27	Medium
Pulp and Paper	Integrated/ market mill	7-20%	-	Medium
Other	Natural gas processing	2-65% (100%)	0.9-8 / 0.05-4.4	- depending -
	Biogas processing	30-50%	-	High

Considering the time frame of 2035, the industry is most likely to have a constant production rate (same as 2015). For big deviations in the projected industrial load, the amounts of CO_2 will be corrected. The yearly production is assumed as flat line 24/7. For the energy sector, the projections of the future energy mix are taken into account in different scenarios. It has to be decided whether the power plants should be modelled with load profiles or whether it should be assumed that local CO_2 storages at each capture site flatten the CO_2 feed. Due to the unavailability of a proper map of the natural gas grid, the filtering process was still in the waiting loop. In 02/2019 a sufficiently detailed map of the natural gas grid was provided by Open Grid Europe (OGE), which will soon be georeferenced into the GIS model. The map contains transport networks of OGE and the other network operators as well as gas storages.
Based on the analytical criteria mentioned above, the annual CO_2 reduction, the increase in energy consumption due to the separation process, and the cost of separation are determined for each site. Subsequently, a first pipeline system is drawn following the routing of the natural gas grid. In various future scenarios, developments such as the coal phase-out and the change in demand for fossil fuels are considered. The transport costs are calculated up to a transfer point at the Dutch border. Whether a transport in the Netherlands will be accounted for, must be clarified. As final results, the CO_2 abatement costs per tonne and the reduction potential for the scenarios within the first option will be determined.
Figure 3.1 shows the CO_2 sources from the E-PRTR database and the (obsolete, not accurate) natural gas grid in the GIS model. It can be seen that most of the large point sources are located on the central east-west axis, most of them in close proximity to the natural gas grid.

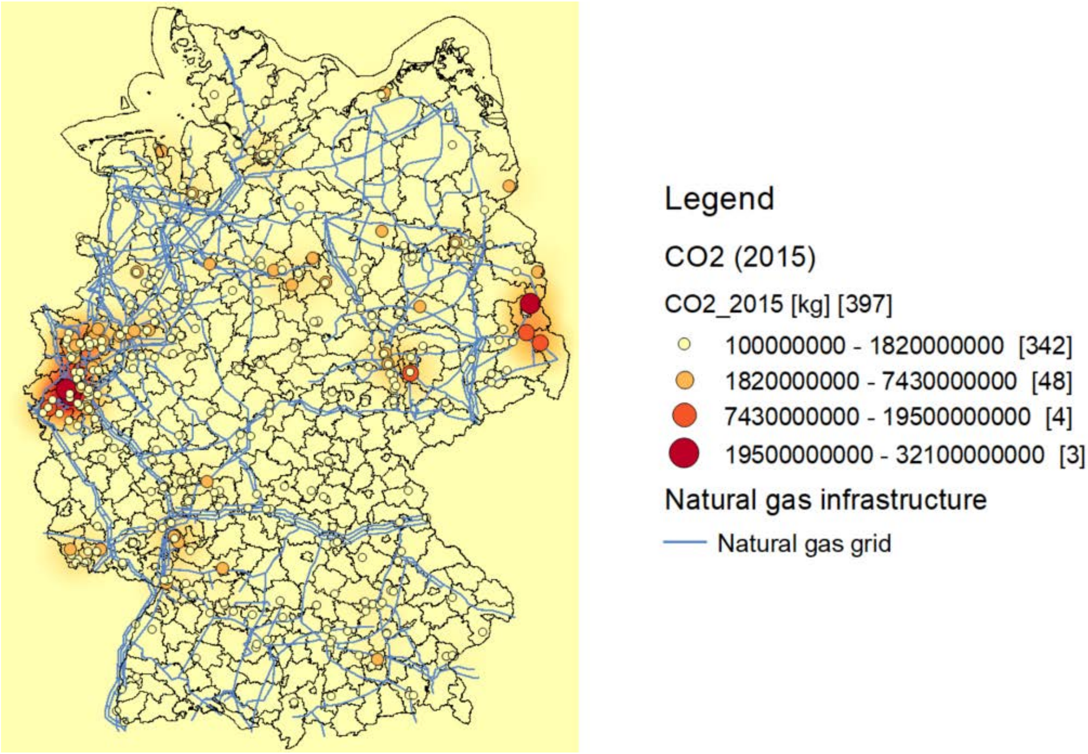

Figure 3.1: GIS Model for option 1, including CO_2 point sources and approximate routing of the natural gas grid.

3.2 Option 2 – Hydrogen Admixture into the Natural Gas Grid

The second infrastructure base option in the German case study aims to determine a maximum admixture level of H_2 in the natural gas grid. The H_2 comes primarily from reformed natural gas in Norway, but the increase of green hydrogen is also considered. Taking into account the three different values which are circulating for the max. concentration of H_2 in the natural gas network (DIN EN 51624: 2%, DVGW G262: 5%, DVGW study: 10%), the base case is set to the highest possible concentration, which does not require large investments and changes for the natural gas consumers. In contrast, the max. feasible admixture level is determined, accepting both changes in the network infrastructure and for the consumers. With regard to the future admixture of green hydrogen, consideration will also be given to converting (redundant) parts of the natural gas grid to 100% H_2. In this scenario, the partial substitution of natural gas is in focus, which means all the connected consumers must be provided with the assumed admixture level.
The modelling of this option is based on the assumption that the whole natural gas grid can be assumed as one volume, of which a percentage can be replaced by H_2. For the overall energy content within the gas grid to remain constant, it has to be considered that H_2 only has 1/3 of the energy by volume when compared to natural gas. To determine the base case and the high admixture values, the restrains and complications both from the gas infrastructure and the gas consumers have to be considered. The compatibility of the natural gas infrastructure will be based mainly on researches carried out by the German Association for Gas and Water (DVGW, [MUE14]). The amount of natural gas within the network is based on the scenarios of the network development plans for the gas infrastructure [FNB17], which forecast a reduction of the demand for natural gas about -20 to -40%. That leaves open capacities for the admixture of H_2. In both cases, the annual avoided CO_2 emissions and the abatement costs will be the main results. Solutions that involve separation of the two gases will be investigated to supply both H_2-only and

CH_4-only applications. However, it is not possible to determine at this point whether this solution can be realized under the respective technological and economic conditions.

3.3 Option 3 – Separate Hydrogen Network

The third base option focuses on a separate H_2 network consisting of both redundant parts of the natural gas grid (e.g. due to the switching from L to H gas) and newly built pipeline sections. The main customers will be the industry and the sectors home heating and mobility. In one scenario, H_2 gas turbines are also considered for power generation. The sector industry here includes the existing H_2 industry, industrial turbines and heating applications. Data on the H_2 demand/production in the H_2 industry sites are provided by data from the project “Roads2Hycom” which is allocating specific amounts of H_2 to each industrial site [MAI07]. Table 3.2 shows a summary of the listed industrial sites, which cover a total of 21.9 billion Nm³ of H_2 production per year (=100% of the H_2 produced in Germany).

Table 3.2: Industrial H_2 production in Germany [MAI07].

Availability of hydrogen	Process	Source / sink (by-product)	Amount (10^6 Nm³/day)	Amount (10^9 Nm³/year)
Captive (production to cover own demand)	Ammonia	Mostly SMR	15.5	5,657.5
	Captive for chemicals	SMR / POX	3.7	1,350.5
	Refinery	SMR / POX	13.2	4,818
	Methanol	n/a	3.2	1,168
			35.6 (59.4%)	**12,994**
Merchant (production for sale to consumers)	On-site plant	SMR / POX	4.4	1,606
	Feed in pipeline	SMR	1.0	365
			5.4 (0.9%)	**1,971**
By-product	Chlorine potassium/sodium hydroxide electrolysis	15% transported via pipelines	3.9	1,423.5
	Ethylene, Styrene, Acetylene	n/a	4.3	1,569.5
	Coke oven gas	n/a	10.7	3,905.5
			18.9 (31.6%)	**6,898.5**
SUM			**59.9 (100%)**	**21,863.5**

Table 3.2 shows that around 30% of the H_2 production in Germany is a by-product of other reactions and should therefore not be substituted by Norwegian H_2 in the considerations of the German case study. However, more than 70% (14 billion Nm³ per year) of industrial H_2 derives from merchants or the captive production and can therefore be replaced by decarbonized H_2 from Norway. According to the projections of the Öko-Institut scenarios, the demands for Ammonia and Methanol will be constant. Only the production of mineral oil products will most likely see a huge decline due to the decarbonisation of the mobility sector [OEK15].

With regard to the house heating sector, this study will consider the supply of heat grids with stationary fuel cells as CHP application. A replacement of heating systems in houses (as well as changing the gas distribution infrastructure to H_2) is not planned. The data for the distribution of heat grids are taken from the statistical departments and projected to 2035. The mobility sector takes into account public and private transport. Public transport applications in this option will be buses and trains powered by fuel cells, using projections for their future market penetration in

different scenarios. Similarly, the penetration of fuel cell vehicles (FCV) is considered in different scenarios for the private mobility sector, considering the antagonistic market penetration with electric vehicles. In order to allocate the H_2 demand for the mobility and heating sectors, statistical methods and data will be applied to distribute the projected data across the NUTS3 regions in Germany. H_2 distribution centres are assumed in the centroids of these regional areas, factoring in an average transport range (most likely with H_2 trailers) in each regional area.
Figure 3.2 shows the GIS model for option 3, including the H_2 industry, the natural gas network and gas storages, the existing H_2 network, H_2 fuel stations, and a possible extension of the H_2 pipelines to supply more H_2 industry sites. The modelling for the supply of mobility and heating applications will result in more hot spot areas that can also be connected to the new infrastructure.

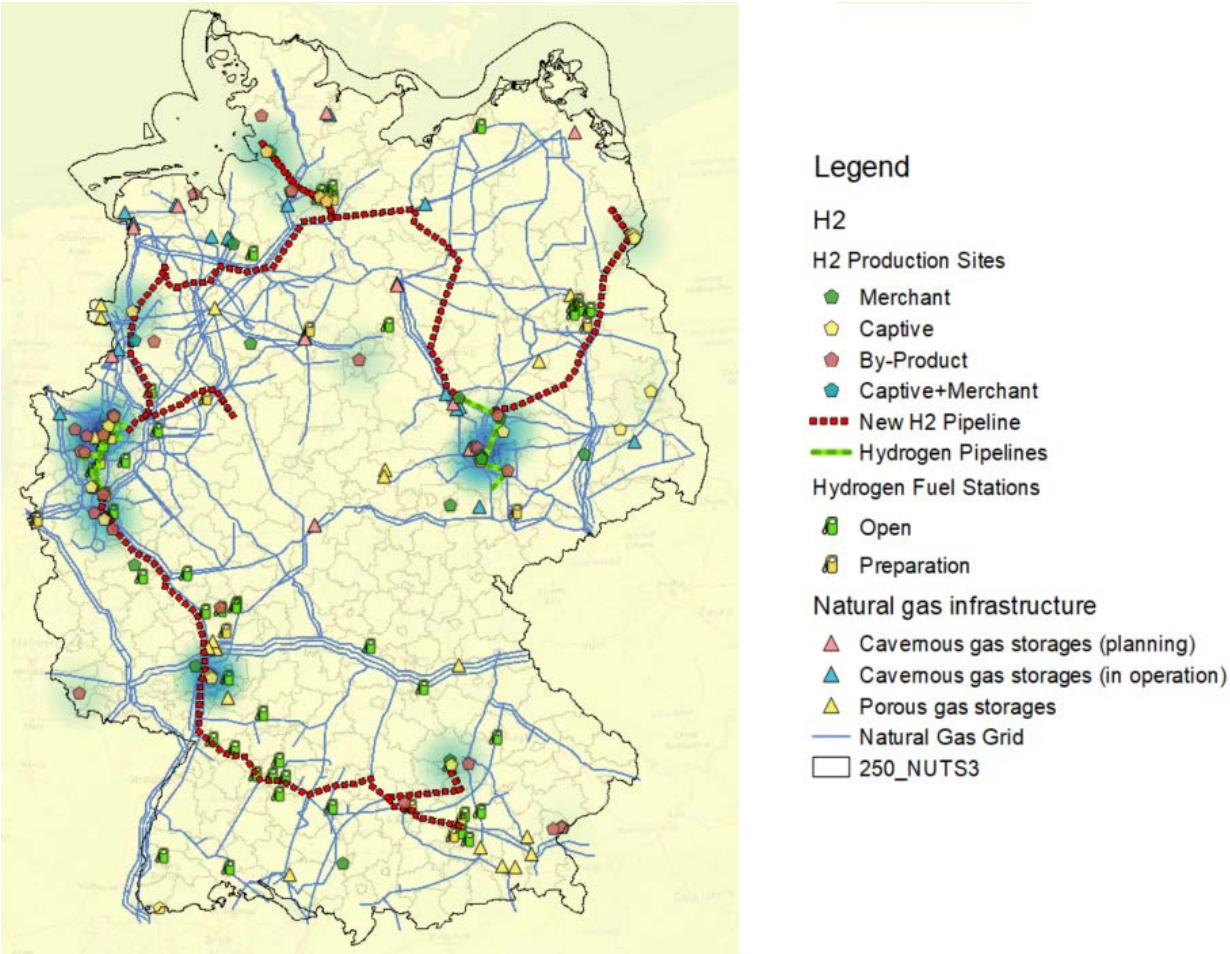

Figure 3.2: GIS Model for Option 3, including H_2 sites, natural gas infrastructure, H_2 fuel stations and existing and new built H_2 pipelines.

3.4 References

[FNB17] FNB GAS (ED.): *Szenariorahmen für den Netzentwicklungsplan Gas 2018-2028 der Fernleitungsnetzbetreiber*. 2017.

[FNR14]: FACHAGENTUR NACHWACHSENDE ROHSTOFFE E. V. (FNR): *Leitfaden Biogasaufbereitung und -einspeisung*. 2014.

[GOE15] GÖRNER, K.: *Umwandlungsprozesse bei fossilen Energieträgern*. In: FISCHEDICK, M. ET AL.: CO_2*: Abtrennung, Speicherung, Nutzung*, pp. 153–254. 2015.

[IPC05] GALE, J. ET AL.: *Sources of* CO_2. In: *Intergovernmental Panel on Climate Change (IPCC) Special Report: Carbon Dioxide Capture and Storage*, pp. 77–101. 2005.

[MAI07] MAISONNIER, G. ET AL.: *Industrial surplus hydrogen and markets and production.* In: *Roads2HyCom DELIVERABLE 2.1 AND 2.1a*. 2007.

[MUE14] MÜLLER-SYRING, G. ET AL.: *Abschlussbericht Wasserstofftoleranz der Erdgasinfrastruktur inclusive aller assoziierten Anlagen*. 2014.

[OEK15] ÖKO-INSITUT E.V. (ED.): *Klimaschutzszenario 2050. 2. Endbericht*. 2015.

[VDA 16] VON DER ASSEN, N. ET AL.: *Selecting* CO_2 *Sources for* CO_2 *Utilization by Environmental-Merit-Order Curves*. In: Environ. Sci. Technol. 50, pp. 1093−1101. 2016.

4 MACROECONOMIC ASPECTS

4.1 Macroeconomic Approach

4.1.1 Objectives and Approach

The primary objective of the macroeconomic approach is to assess the conditions that foster or hinder the transition towards a low-carbon economy. By using a complexity economics approach, we evaluate the different infrastructure options in terms of political and economic feasibility. For this purpose, we conduct an economic-centred stakeholder analysis that include economic but also non-economic aspects.

First, we develop qualitative, descriptive scenarios to deal with the high level of complexity and uncertainty related to the future development of the energy system and sector. As a result, we get a systematic picture of dynamics, main drivers and stakeholder that mainly determines the development of the German energy system. These qualitative scenarios will be used as a framework to evaluate the infrastructure options. Intermediate results from the other disciplines will be used to interpreted and validate the scenarios.

Second, we conduct a stakeholder analysis to better understand the stakeholder dynamics which will be adjusted to fit the combined analysis of the base cases and best case. Additionally, the scenarios can be used as a base for providing policy recommendations and orientation for decision makers who are involved in the energy sector and its decarbonisation.

4.1.2 Method and Process

In general, the method of scenario analysis has its origin in the academic field of future studies [BIS07,5]. Although there is no uniform definition for scenario in the literature [BRA05,796], scenarios describe “a possible situation in the future, based on a complex network of influence factors” [GAU89,115]. In this sense, “[t]hey reflect different assumptions about how current trends will unfold, how critical uncertainties will play out and what new factors will come into play” [KOS08,12]. From a methodological perspective, scenario analysis is a tool and thought experiment to explore how the future might look. It stimulates creative thinking and allows to include the unthinkable [SHE03,8; KOS08,12; BRA05,798; SCH95,27]. Qualitative scenarios differ from quantitative prognosis and forecasting methods in the sense that they do not aim to identify the most likely future development but do provide a wide range of possible and plausible future developments without assigning probabilities [GRU02,2; KOS08,13]. Thus, qualitative scenarios are not predictions but a tool to deal with high level of complexity and uncertainty. Furthermore, it is a tool to allow to include different disciplines perspectives and feedback from different stakeholders, which is a key feature of the German case study of ELEGANCY.

The qualitative scenario development for ELEGANCY is based on the methodology of scenario-management [FIN16]. Figure 4.1 displays the process of scenario development which is briefly described in the following.

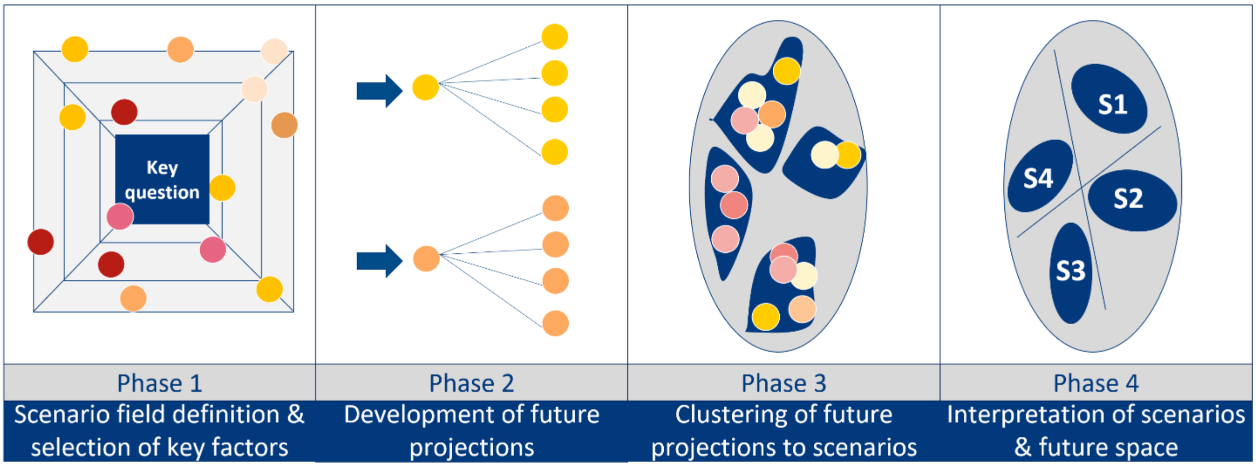

Figure 4.1: Phases of qualitative scenario management.

Phase 1: Scenario field definition and selection of factor selection

The aim of phase 1 is to define the scenario field and to select key factors. The scenario field is defined by key aspects such as target group, time horizon and scenario objective. Subsequently, the scenario field is structured and visualized in form of a system image and described by a large number of influence factors. To reduce the number of influence factors to 15-25 key factors, an interconnection-relevance analysis is applied. These key factors represent the driving forces of the scenario field and are the starting point for the scenario development.

Phase 2: Development of future projections

For the scenario development, future projections are identified for each key factor. These future projections describe possible pathways of the future development of a specific key factor. While it is not the aim to identify the most likely future development in terms of probability, it is about to develop a holistic picture of future development that also includes extreme events.

Phase 3: Clustering of future projections to scenarios

To develop alternative future scenarios, highly consistent future projections are combined in phase 3 to raw scenarios. For this combination, a consistency analysis is used that clusters all future projections to consistent projections bundles. These projection bundles are reduced to an adequate number of 3–7 raw scenarios. As a result, each raw scenario contains one future projection of each key factor.

Phase 4: Interpretation of scenarios & future space

In the last phase, a comprehensive descriptive of every raw scenario is developed based on the list of future projections of each raw scenario. Subsequently the scenarios are interpreted: What scenario is most likely? Which scenario is desirable, which one is not? Comparing the scenarios, what are the main differences or similarities? What should be done today to realize a desirable scenario or prevent an undesirable scenario to materialize?

As figure 4.2 highlights, the scenarios are developed by a core economic scenario team, that runs through all process phases. To include the feedback from different disciplines and stakeholder, two feedback rounds are included in the process of scenario development. In a first feedback round, the German RUB case study team provided feedback for the conceptual work of phases 1 and 2. To not neglect important aspect, we discussed about the completeness of the system image and key factors as well as included discipline-specific feedback in the development of particular future projections. This exchange is crucial since the scenarios include different perspectives and thus not only economic but non-economic aspects. In a second feedback round we presented the raw scenarios to external stakeholder. For this purpose, we invited regional energy experts from different fields to a workshop with the aim to discuss the raw scenarios. Their feedback on the different raw scenario will be integrated in a next step into the description as well as the interpretation of the scenarios.

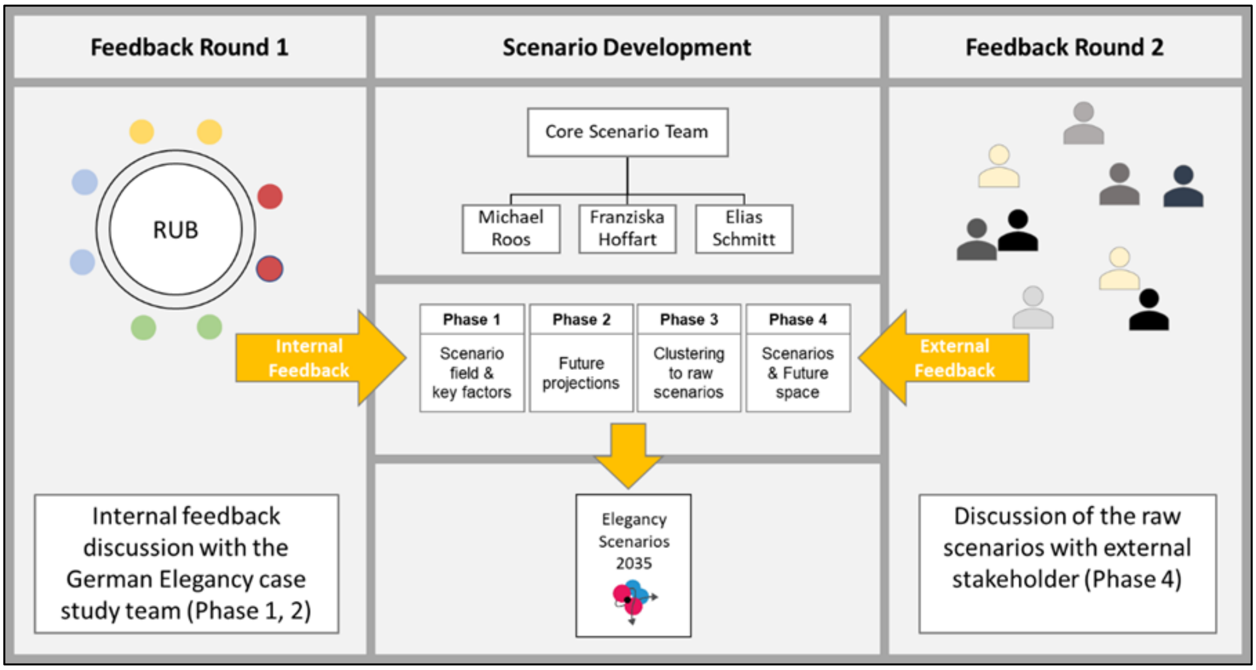

Figure 4.2: Scenario Development & Feedback Process.

4.2 Scenario Development and Intermediate Results

4.2.1 Phase 1: Scenario Field and Key Factors

As a first step, the scenario field is defined by key aspects such as topic area, time horizon, target group and scenario objective: The ELEGANCY scenarios focus on the development of scenarios which describe alternative future developments of conditions that are relevant for a possible gas infrastructure modification for the year 2035. Political and private decision makers that are involved in the German gas sector and related sectors are selected as a target group. The aim of the scenario development is twofold. Within ELEGANCY, the scenarios serve as a framework to evaluate the different infrastructure options. Beyond the project, the scenarios aim to provide orientation for the beforementioned decision makers. The objective of the scenario development is defined as follows: The scenario describes the development of underlying conditions that are relevant for an expansion of the German gas network with the aim to reduce emissions in the years 2035 within the scope of energy transition and sector linkage. The scenarios represent alternative pathways of future development and have a regional, specific focus. They apply to the context of Germany exclusively.

In a second step, a structured system image was developed that visualizes the scenario field and is structured in system levels and topic areas (see figure 4.3). It captures the complexity in a structured hierarchically way and represents a good tool to communicate the scenario field. The first and second sector system levels display the gas and electricity sector which are regarded as interlinked. They are characterized by topic areas such as producers (gas sector) or electricity production (electricity sector). The gas and electricity sector represent the supply side of the energy sector and are connected to the consumer side via the energy infrastructure. The energy infrastructure is represented by system level 3 and contains the gas and electricity network. System level 4 represents the demand side and brings together coupled sectors such as industry, mobility and heating sector. This system level also includes energy politics which mainly shapes the energy transition and thus the development of the supply and demand side. These four system levels form the core area of the scenario field and are embedded in the specific German environment (system level 5) and the general international environment (system level 6). These two rather general system levels represent framework conditions that shape the development of the core area such as economic conditions, technologies, effects of climate change or international legislation.

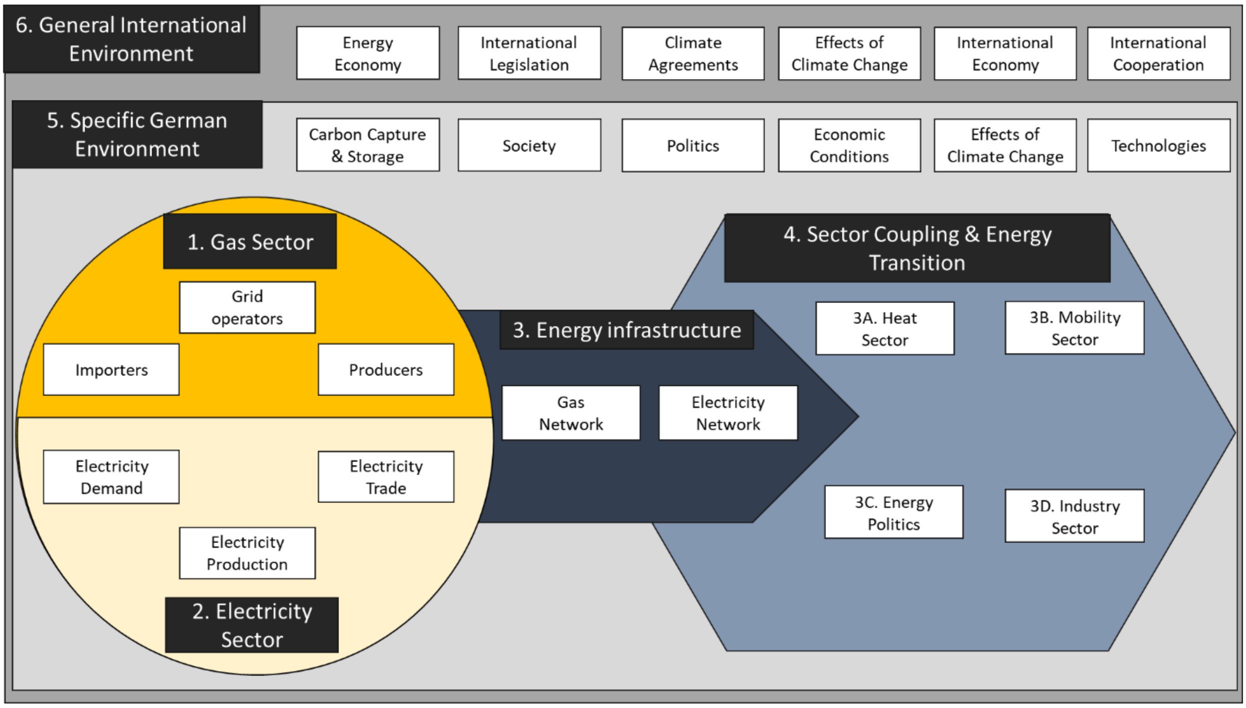

Figure 4.3: Scenario system image.

In a third step, the core team determined 111 influence factors that were assigned to a specific topic area in a brain storming process. Each of these factors describe specific aspects of the scenario field whose development pathways are important for the scenario objective.

To reduce the number of influence factors and to select key factor, an interconnection analysis is used in the fourth step. Each influence factor is evaluated in terms of activity and passivity and is visualized in an active-passive grid. While the activity value determines to what extent a factor influences other factors, the passivity value determines to what extent the factor is influenced by other factors. In the active-passive grid the influence factors are classified in the four categories independent factors, indicators, system nodes and levers (see figure 4.4).

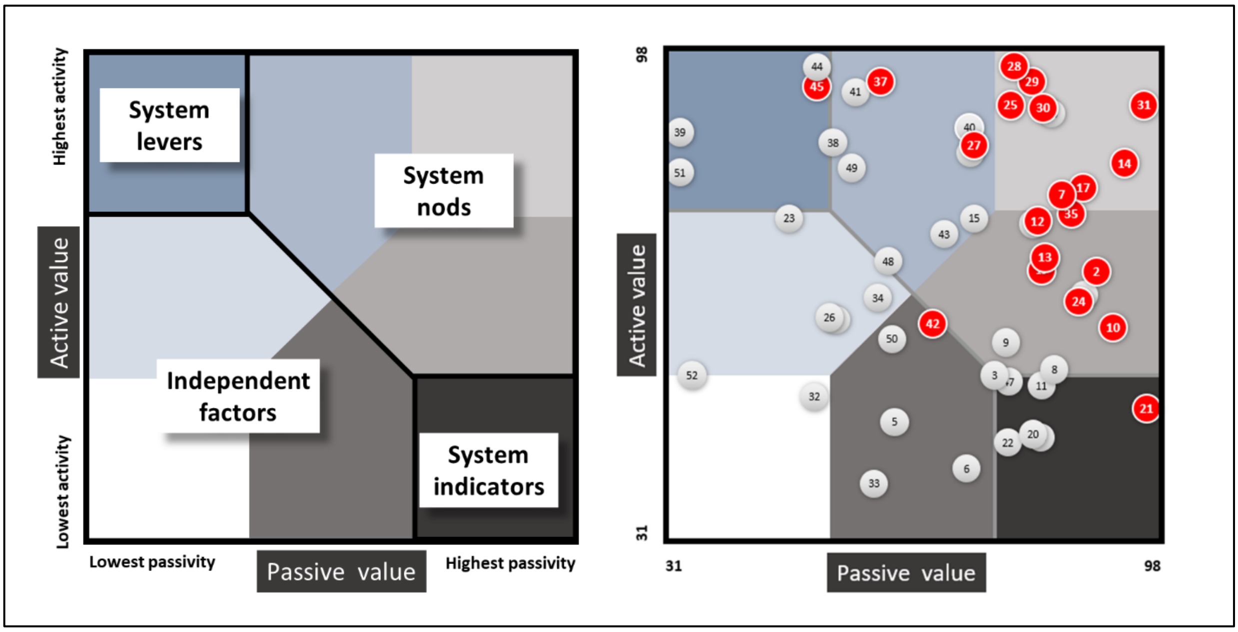

Figure 4.4: Classification of influence factors and selection of key factors.

As the name indicates, independent factors have a low interconnection to the whole system, both in terms of activity and passivity. Due to their marginal effect on the system's dynamic, independent factors can be neglected. Indicators have a low influence on the whole system (low activity) but are highly influenced be other factors (high passivity). In this sense, indicators display changes of the whole system. System levers have a high influence on the whole system (high activity) with hardly any feedback effects (low passivity). Changes in this factor effect systems dynamic in many ways. System nodes are highly connected to the whole system, both in terms of activity and passivity. Changes of these factors result in complex reciprocal effects, which are hard to predict and should be included as key factor.
Based on this analysis, 20 key factors were initially selected. We refined these factors based on internal revisions and workshop feedback to the number of 23. Table 4.1 lists all key factors and classifies them in categories different to the topic areas.

Table 4.1: Key Factors.

Categories	Related Key Factors
Outcome	1) Realization of National Climate Goals
Stakeholder	21) Private Sector Investors in Gas Sector
	22) Character of Public Policy
	15) Power of Lobbyism
	8) Power of Public Interest Groups
	7) Behavior & Public Acceptance
Measurements	2) Phase Out & Phase In: Fossil & Renewable Gas
	4) Cost of Carbon
	12) Carbon Capture Technologies
	17) Lignite Energy Phase Out
	23) Governmental support of transformation technologies
	9) Fuel of Road Traffic
	18) Heating

Sector-specific development	11) German Production of H_2
	19) H_2 Power Plants
	20)Technological Progress & Market Maturity
Infrastructure development	5) Electricity Network Expansion
	14) National Gas Network Expansion
	6) Electricity Production
	10) German Gas Demand
	16) Decarbonisation of Natural Gas
	13) Electricity Consumer Price
	3) Price Natural Gas

4.2.2 Phase 2: Development of Future Projections

In phase 2, the key factors are defined in more detail by developing future projections. These future projections show possible pathways of future development that are relevant for the scenario objective. For each key factor 4–5 future projection are developed by combining two dimensions, as it is shown in figure 4.5 with the example of key factor 6.

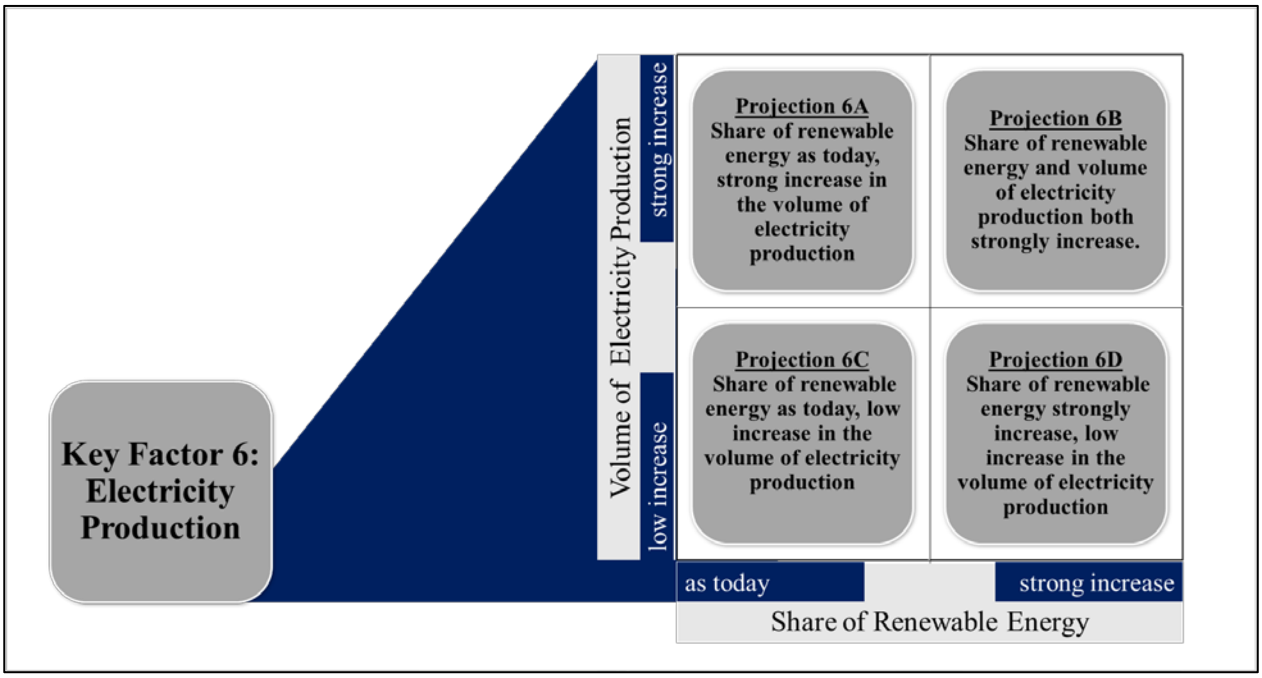

Figure 4.5: Example of future projections.

4.2.3 Phase 3: Clustering of Future Projections to Scenarios

In phase 3, the different future projections are combined to projection bundles according to their logical consistency. For this purpose, a consistency matrix is used to analyse the relation between the future projections (relation rating: highly consistent, consistent, independent/neutral, partially inconsistent, totally inconsistent). As a result, we developed six raw scenarios by using a cluster analysis. A raw scenario consists of 23 highly consistent future projections, to be more precise, one of each key factor. We presented these raw scenarios to external energy experts in a workshop (feedback round 2) to discuss the experts' opinion and feedback on the scenarios.

As a preliminary interpretation, the raw scenarios can be classified according to their overall level of transformation, the level of conflict and the level of commitment of stakeholder towards the transformation. The overall level of transformation appears to be most characterizing since it mainly determines the feasibility of the different infrastructure options. One raw scenario shows no transformation, while three raw scenarios show a low and two raw scenarios a high level of overall transformation. Although there is no single most important key factor, the raw scenarios reveal that the stakeholder dynamics play a central role since the interactions between the stakeholder mainly determine the scenario setting and thus the overall level of transformation. We identified five crucial stakeholder groups that are represented by the key factor that is indicated in brackets: political decision makers (22. Character of Public Policy), citizens & society (7. Behavior & Public Acceptance), public interest groups (8. Power of Public Interest Groups), economic lobby groups (15. Power of Lobbyism) and investors (21. Private Sector Investors in Gas Sector). According to the workshop feedback, the three low level transformation scenarios are the most realistic and most interesting. This is due to the relation of the level of conflict and the level of commitment towards the transformation that differs strongly and determines the overall level of transformation. The workshop participants identified different main drivers which can be explained with their different discipline backgrounds. However, they agreed that the availability and progress of technologies plays a minor role. Whether H_2 and carbon capture technologies are used or not, depends on other key factors. Besides, the raw scenarios reveal that for modification of infrastructures the context, legal framework and long-term planning certainty plays a crucial role, which was confirmed by the workshop participants. In addition, the commitment of all stakeholder groups towards the transformation is relevant. This means, on the one hand, that bottom-up commitment of the economy and of society is not sufficient to foster a high overall level of transformation, when political commitment is missing. And on the other hand, political decisions are necessary but not sufficient for a high level of transformation, which also requires economic and societal commitment.

These first results will be further refined in the next steps (Phase 4) before they will be used to evaluate the infrastructure options. To get a holistic picture of stakeholder dynamics, the results of the scenario development will also be combined with the results of the sociological approach. While both approaches have a focus on stakeholders, the macroeconomic approach focuses on the identification of main drivers, stakeholder and dynamics, while the sociological approach provides reason and arguments related to stakeholder groups.

4.3 References

[BIS07] BISHOP, P.; HINES, A.; COLLINS, T. ET AL.: *The current state of scenario development. An overview of techniques*. In: *Foresight* 9, pp. 5–25. 2007.

[BRA05] BRADFIELD, R.; WRIGHT, G.; BURT, G. ET AL.: *The origins and evolution of scenario techniques in long range business planning*. In: *Futures* 37, pp. 795–812. 2005.

[FIN16] FINK, A.; SIEBE, A.: *Szenario-Management. Von strategischem Vorausdenken zu zukunftsrobusten Entscheidungen.* 2016.

[GAU89] GAUSEMEIER, J.; FINK, A.; SCHLANKE, O. ET AL.: *Scenario management: An approach to develop future potentials*. In: *Technological Forecasting and Social Change* 59, pp. 111–130. 1998.

[GRU02] GRUNWALD, A.: *Technikfolgenabschätzung. Eine Einführung*. Berlin: Ed. Sigma. 2002.

[KOS08] KOSOW, H.; GAßNER, R.: *Methods of future and scenario analysis. Overview, assessment, and selection criteria*. Bonn: Dt. Inst. für Entwicklungspolitik. –

URL: http://www.die-gdi.de/CMS-Homepage/openwebcms3.nsf/(ynDK_contentByKey)/ANES-7LZJRH?Open&nav=expand:Publikationen;active:Publikationen\\ANES-7LZJRH. 2008.

[SCH95] SCHOEMAKER, P.: *Scenario planning. a tool for strategic thinking*. In: *Sloan Management Review* 36 no. 2, pp. 25–40. 1995.

[SHE08] ROYAL DUTCH SHELL: *Shell energy scenarios for Germany*. – URL: https://www.shell.com/energy-and-innovation/the-energy-future/scenarios/what-are-scenarios/_jcr_content/par/tabbedcontent/tab/textimage_25172244.stream/1504104048141/c1c44f23149c7604853b92e1be624a6ac49cd08fcfc269890448bb62f6cd0499/shell-energy-scenarios-germany.pdf. 2018.

5 LEGAL ASPECTS

5.1 Legal Approach

The legal perspective of the German case study looks at legal costs, risks and constraints of the different options for developing the German infrastructure under scrutiny as well as the legal framework for measures attached to the implementation of the options. Therefore, the existing law is analysed. This analysis also covers systematic lines, lacunae and potentials for further development in the current law. Based on this, possible future developments of the legal background and their legal constraints are discussed.
This legal research touches several problems, which are examined with certain focus areas. The different legal problems and focus areas that are relevant for the German case study have been presented in D5.5.1 in more detail.

5.2 Legal Landscape of Applicable Law for Pipeline Transport

A major step for the legal analysis is the mapping of the relevant legal landscape in regard to the applicable regimes. This mapping provides a first overview of the relevant law and its systematic relations. And, more importantly, it provides a first connecting point for any further in-depth analysis. The legal landscape presented here covers the most relevant specific rules for pipeline transport in the scope of the German case study. Yet, it does not cover all relevant law; the different relevant legal problems are also ruled by legal provisions without a specific connection to pipeline transport. Although these provisions have a relevant effect on certain issues, they do not affect the overall legal landscape of pipeline transport.
The scope of the German case study encompasses pipelines for the transport of CO_2 for CCS (option 1), pipelines for the transport of natural gas including other gases injected into the natural gas grid (option 2) and pipelines for the transport of H_2 (option 3). In regard to H_2 transport, H_2 for energetic purposes and H_2 as feedstock have to be differed because the special regime for energy networks comes into question only for H_2 energy pipelines. Although option 3 aims at a dominant role of energetic purposes, H_2 as feedstock will be considered as well. This rounds the legal landscape off, allows to show all possible regimes in respect of legal uncertainties and opens the examination up for different actual usages of H_2.
In Germany, there are actually natural gas pipelines transporting also H_2 and H_2 pipelines for H_2 as feedstock as well as respective legal regimes. For the transport of CO_2 for CCS, there is at least a comprehensive legal regime. There are currently no pipelines to transport pure H_2 for energetic purposes and there is no legal regime designed for it; H_2 is regulated explicitly only in the context of natural gas pipelines.

5.2.1 Dimensions of the Legal Landscape

The dimensions of the legal landscape in Germany are next to the different kinds of pipelines (CO_2, natural gas, H_2 for energetic purposes, H_2 as feedstock) the size of the pipeline, the level of regulation (international public law, EU, Germany, state level) and the area of law.
Relevant areas of law that specifically address aspects of pipelines and transport and are therefore included in the legal landscape are:

- the administrative procedure in regard to construction permits, including environmental impact assessments (EIAs);
- expropriation law;
- planning law, including special instruments for planning and coordination;
- unbundling of operators;

- competition law in regard to operators, including access regime, tariffs regulation and control of abuse;
- licensing for operators;
- operator duties in regard to system responsibility;
- safety, including major accidents law;
- trade, especially cross-border trade and transport;
- technical rules, especially in regard to interoperability.

Although this list is not comprehensive and does not cover all areas of specific pipeline and transport law, these areas will convey an appropriate overview.

Additionally, the following aspects will be taken into account for the legal landscape:

- central harmonisation by EU law;
- competent authorities;
- integration in the Emission Trading System (ETS) and certificate schemes.

Harmonisation and competent authorities are cross-section issues that highlight the structure of the legal landscape in their own ways. The integration into existing schemes for climate protection does not specifically address pipeline or transport issues, yet the look at this area of law locates the legal landscape in regard to pipeline infrastructure in the broader landscape of climate protection and raises some relevant general issues.

Not all of these landmarks are relevant for all pipeline regimes. Yet, the lack of stipulations also adds to the characteristics of the respective landscape.

5.2.2 Applicable Law to the Different Pipeline Regimes

5.2.2.1 Carbon Dioxide Pipeline Regime

The introduction of CCS and the need for regulatory action have been subject of intense political debate on national and EU level, which has produced a comprehensive legal framework for CCS. The focus of the debate and the corresponding legislation was put on the storage aspects while the transport aspects were considered only marginally. In the short time since, there has been only little further legal development. Especially, the general shift of the focus of the technical debate from onshore storage at the site of CO_2 production to offshore storage with long-distance transport from the site of production has never fully translated into the legal framework. In particular in Germany, CCS is considered politically unfeasible and neither the political debate nor the legal background for the whole topic area has received much further attention [BUN18]. This background is reflected by the regulatory density and the technical quality of the relevant regulation in detail, especially on the national level.

The EU considers CCS as a possible contribution to implement the CO_2-reduction goals and is willing to accompany the technical development on the regulatory level. The core provision for harmonisation in respect of CCS is Directive 2009/31/EC (CCS Directive) in regard to carbon capture, transport and storage, which allows much flexibility for the member states. CCS is also – often by amendment – considered in other legal instruments, such as Regulation (EU) 347/2013 (TEN-E Regulation) or Directive 2003/87/EC (EU ETS Directive). On the international public law level, especially rules for the protection of the sea are relevant for (offshore) CCS, the 1996 London Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter in particular [DIX15].

In Germany, most issues in the area of CCS are covered by the Carbon Dioxide Storage Act (KSpG), which implements the CCS Directive. The transport of CO_2 for CCS is mostly covered by § 4 KSpG, which refers to other stipulations of the KSpG as well as to stipulations in the Energy Industry Act (EnWG) and in the Federal Administrative Procedures Act (VwVfG). The references integrate the CCS law into the general regimes. Additionally, there are specific rules for CCS in other acts and general rules that are relevant for CCS and CO_2 transport. A lack of attention and the abundance of references obscure the details of the CO_2 pipeline regime: Not all references can be read literally; in particular, the references of § 4 KSpG were not adjusted to a major reform of the federal planning decision procedure in 2013 wherefore the literal references have to be corrected accordingly.

For the construction of all CO_2 transport pipelines for CCS, a planning decision of the competent authority is required. A planning decision concentrates all special procedures, includes the participation of the public and is more stable than regular administrative decisions. The administrative procedure copies the procedure for natural gas pipelines and adds minor modifications: Especially, the planning decision procedure applies to all sizes of pipelines and demands special information of the public before the proper procedure. The regime for EIAs pursuant to the Environmental Impact Assessment Act (UVPG) and its first Annex parallels (technically coherently) the regime for pipelines for liquefied gas; thus, the regime is in regard to the size categories slightly stricter than the regime for natural gas pipelines (starting at a diameter of 150 mm). The competent authority is determined by state law; in North-Rhine Westphalia, in absence of any specific stipulation, the general regional administration is competent. Expropriations for CO_2 pipelines are governed by § 4 (5) KSpG in connection with § 15 KSpG: As fas ar CO_2 emissions are reduced for the purpose of climate protection, any land necessary for the construction of a pipeline – even for the transport of CO_2 abroad – backed by a positive planning decision is legal. Additionally, § 4 (3) KSpG refers to the system of accompanying rights and powers for energy pipelines pursuant to the EnWG.

There are no specific CO_2 pipelines related rules for special and general planning. Thus the general planning law applies, which can also cover long-distance CO_2 pipelines as regionally significant projects. In North-Rhine Westphalia, regional planning provisions stipulate some general rules for pipelines, including CO_2 pipelines. As a special tool for planning and coordinating specific projects for CO_2 pipelines, the TEN-E Regulation defines CO_2 pipelines for CCS as energy infrastructure and allows to identify them as projects of common interest.

For CO_2 system operators, there are only limited operator duties. Pursuant to § 33 KSpG, operators have in general to provide non-discriminatory access and connection to their pipelines. This provision is controlled by the federal regulatory authority, the Bundesnetzagentur (BNetzA). The authorisation for further regulation in this area has not been used yet.

In respect to the safety of the pipelines, § 4 KSpG refers to the corresponding provision for energy pipelines, § 49 EnWG. This does not include the power of the BNetzA to issue further safety rules but refers to the relevance of the technical rules of the DVGW. The competent authority for control in regard to safety is determined by state law. In contrast to major accidents on the storage site, there are no special rules for major accidents in respect to CO_2 transport. An ordinance on CO_2 pipeline safety has not been enacted despite a respective authorisation. Neither, other specific rules for major accidents are applicable: The Transport Pipeline Ordinance (RohrFLtgV) is not applicable because CO_2 does not fit the requisite hazard characteristics; the Gas High-Pressure Pipeline Ordinance (GasHDrLtgV) is not applicable because it is only applicable to energy pipelines. General rules for major accidents can only be derived from the general safety regime of § 4 KSpG in connection to § 49 EnWG.

Following the CCS Directive, § 4 KSpG explicitly allows the cross-border transport of CO_2 for CCS. But there are no further provisions for more details or accompanying trade rules. For the transport of CO_2 as waste to the Netherlands, the free movement of goods and its peculiarities in respect to waste have to be considered. Additionally, the London Protocol, which forbids the export of CO_2 for offshore CCS, has to be taken into account.

Technical rules for CO_2 do not exist, despite some authorisations for respective ordinances. Neither are there legal mechanisms for coordination or to promote interoperability. At most, the

duty of non-discriminatory conditions for access and its limits in connection to the technical specifications for the injection of CO_2 into the storage site pursuant § 24 KSpG can provide some basic technical harmonisation from the legal perspective.
By now, CCS is completely integrated into the ETS-system. Captured CO_2 does not demand any emission allowances, while CCS, including the transport of CO_2, demands appropriate allowances in respect of leakages.

5.2.2.2 Natural Gas Pipeline Regime

The natural gas market and its pipeline networks are a mature and highly regulated economy. The extensive natural gas pipeline regime also refers to injections of H_2, though H_2 have not been in the focus of the legislator yet.
On EU level, Directive 2009/73/EC (Natural Gas Directive) provides a comprehensive harmonisation of natural gas networks, which is supplemented by Regulation (EC) 715/2009 (Transmission Regulation) which focuses on the cross-border transport of natural gas. The Natural Gas Directive explicitly covers other gases injected into the natural gas grid, such as H_2.
On the national level, natural gas pipelines are governed by the EnWG and supplementing ordinances in regard to different aspects of the natural gas pipeline regime. This regime explicitly encompasses H_2 for injection into the natural gas grid as well, but the relevant provision is literally restricted to H_2 produced by electrolysis. Whereas the legal consequences of this restriction are not clear in regard to details, it does not question the application of the natural gas pipeline regime to natural gas pipelines when H_2 produced by other methods is actually injected into the natural gas grid.
For the construction of a natural gas pipeline with a diameter of more than 300 mm, a planning decision, which concentrates the procedure at one single authority (determined by state law), is required. For smaller natural gas pipelines, single permits and procedures for the different aspects of the construction at different authorities are required. Accordingly, the regime for EIAs starts at a diameter of 300 mm. Additional rules for the administrative procedure for the construction of all high-pressure natural gas pipelines are provided by the GasHDrLtgV. Expropriations for natural gas pipelines are governed by § 45 EnWG: For constructions based on a planning decision, necessary land for the construction can be expropriated; for the construction of other natural gas pipelines, it has to be determined by the competent state authority if the expropriation is appropriate for energy supply. The expropriation clause is embedded in a complex system of rights and special powers to promote the construction.
EU law for the harmonisation of natural gas networks and its national implementation in the EnWG provides for many different legal instruments to coordinate and plan the construction and development of the natural gas network, including network development plans on EU and national level, regional investment plans as well as the cooperation of the transmissions operators in the framework of the ENTSO-G. Additionally, Regulation (EC) 713/2009 (ACER Regulation) provides for the cooperation of the regulatory authorities and the TEN-E Regulation allows to identify specific projects for the development of the natural gas grid as projects of common interest. Just as CO_2 pipelines, regionally significant natural gas pipelines are subject to general planning. The Regional Planning Act (ROG) and the accompanying Regional Planning Ordinance (RoV) even demand a special procedure for natural gas pipelines with a diameter of more than 300 mm to ensure the compatibility with regional planning. In North-Rhine Westphalia, the general rules for pipelines of the regional planning provisions apply to natural gas pipelines as well.
The operators of natural gas pipelines and especially natural gas transmission pipelines have to comply with manifold legal duties pursuant to the EnWG and the Transmission Regulation to safeguard the security of supply and to enforce the regulated market, which at the core demands

to grant access to the networks without discrimination. The relevant provisions address unbundling, the requirement of licensing and certificates (for transmission pipelines), network access, the connection to networks, tariffs and system responsibility as well as supporting mechanisms. For most of these aspects, the BNetzA (or the state regulatory authority for certain issues of small networks) is the competent authority; for some aspects, especially if related rather to the facilities, the competent authority is determined by state law.

Safety requirements are provided by § 49 EnWG and the GasHDrLtgV. The ordinance covers especially rules for major accidents. The general pipeline law pursuant to the RohrFLtgV is displaced by these rules. Additionally, the BNetzA is authorised to issue technical rules for safety, while the state law determines the authority which is competent to enforce the safety requirements. § 49 EnWG refers to technical rules provided by the DVGW, which has already addressed H_2 in natural gas pipelines.

The extensive harmonisation for natural gas networks at EU level aims at an effective free trade and transport of natural gas within the internal market, which is in principle already guaranteed by the free movement of goods. The harmonisation is supported by further regulatory instruments to tackle technical problems for cross-border trade and transport in the highly regulated natural gas networks, especially the network codes.

To ensure interoperability of networks is part of the system responsibility of system operators pursuant to the EnWG. The effective interoperability is supported by multiple layers of technical rules. The operators have to issue minimum technical requirements pursuant to § 19 EnWG, which ensure interoperability, especially in regard to other gases. On EU level, based on the non-binding framework guidelines of the Agency for the Cooperation of Energy Regulators (ACER), the ENTSO-G develops network codes, which are adopted by the Commission. Regulation (EU) 2015/703 (Interoperability Network Code) provides a framework for promoting interoperability, especially for cross-border transport.

Whereas the German Gas Network Access Ordinance (GasNZV) provides mechanisms to trade biogas to specific customers, these mechanisms do not extend to other states and do not cover H_2 produced from natural gas. The new Directive (EU) 2018/2001 (Renewable Energy Directive) stipulates the introduction schemes for guarantees of origin for all kinds of renewable energy by 30 June 2021, explicitly including biogas and H_2 produced with renewable energy (art. 19). There are no certificates or comparable mechanisms backed by the EU or states to “track” “blue hydrogen”. In regard to the emission trading system, whereas the emissions saved by CCS are considered for the production of H_2 and the emissions saved by partly using H_2 are considered for the use of natural gas, the system does not provide a legal mechanism to link the consumption and the production. All customers will benefit from the reduced actual emission of CO_2 while the producer of H_2, in addition to the costs of reforming natural gas and CCS, needs allowances (contrary to a supplier of natural gas).

5.2.2.3 Hydrogen Pipeline Regime for Energetic Purposes

There are no explicit rules for H_2 pipelines for energetic purposes. H_2 is only referred to in the context of injection into the natural gas grid. Nevertheless, the application of general rules for energy pipelines is conceivable and has to be discussed. In any case, the applicable regime for H_2 pipelines is connected to substantial legal uncertainty.

The wording of the Natural Gas Directive suggests the applicability of the directive to H_2 and its pipelines as it stipulates the application to other gases as well [FLE18], but its teleological and systematic context clearly indicates that is directed only at the natural gas market. Pipelines for H_2 that are not connected to natural gas networks are not covered by any specific EU legislation. There are not even specific stipulations in regard to the demarcation of natural gas networks and independent H_2 pipelines.

The national EnWG traditionally covers all energy gas pipelines. Given the fact, that natural gas dominates the energy supply with gas, the current EnWG introduced a system of definitions to clarify the scope in regard to natural gas, which added ambiguity in regard to other gases. Against the background of intense legal uncertainty (both in general and in detail), the better argumentation accepts the general application of the EnWG to H_2 pipelines for energetic purposes, but several stipulations and areas of regulations are specifically aimed at natural gas networks and therefore not applicable to H_2 pipelines.
Following the general application of the EnWG, the provisions for natural gas pipelines in regard to the construction (see above) also apply to H_2 pipelines.
The special instruments for planning and coordination of natural gas pipelines are specifically aimed at natural gas networks and do not apply to H_2 pipelines. Even the TEN-E Regulation does not address H_2 infrastructure. Only the general planning law is applicable to H_2 pipelines as for natural gas pipelines, including the special procedure to ensure the compatibility with regional planning.
Most operator duties in regard to market, competition and regulation are specifically designed for the natural gas network economy and are therefore not applicable to H_2 pipelines, especially the provisions for unbundling and tariffs regulation as well as major parts of the network access regime and the duty to connect. Yet, some provisions are rather general and can be considered for H_2 pipelines as well, such as the general duty not to discriminate in regard to access and access conditions (§ 11(1) EnWG), the duty to connect certain end customers (§ 18 EnWG), the general legal design of the access to the network (§ 20 (1b) EnWG) and the abuse control regime for energy networks (§§ 30–35 EnWG). In contrast, operator duties in regard to system responsibility are in principle applicable to energy H_2 pipelines as well (notwithstanding single exceptions like the monitoring regime pursuant to § 51 EnWG). The duties in regard to the market and in regard to the specific system responsibility are controlled by the BNetzA or the state regulatory authority (like for natural gas) pursuant to the procedural provisions of the EnWG whereas rather facility related duties remain subject to state law and general procedures. System operators of energy H_2 pipelines are required to get a license, that is issued by an authority determined by state law if the operator meets the legal requirements. Certificates pursuant to §§ 4a–d EnWG are not required for H_2 transmission pipelines; for natural gas, these enforce the unbundling regime and are inseparably tied to the Transmission Regulation.
The safety provisions of § 49 EnWG and the GasHDrLtgV are applicable to energy H_2 pipelines as to natural gas pipelines. The technical rules for safety which are issued by the BNetzA do not apply to H_2 pipelines if they are specifically aimed at natural gas (or other gases).
The extensive rules for cross-border trade and transport of natural gas based on the EU harmonisation in the energy sector do not cover H_2 pipelines. Thus, the free movement of goods provides the most relevant legal base for cross-border trade and transport of H_2 in the internal market.
In regard to the technical rules issued by the system operators and to interoperability as an aspect of system responsibility, the EnWG is applicable to energy H_2 pipelines. Yet, the superstructure which EU law provides in respect of natural gas is missing.
For H_2 in H_2 pipelines, there is currently no legal instrument to link the trade and consumption to the production. Even the national biogas mechanism of the GasNZV does not work here as it is integrated into the network access regulation, which in essence is not applicable to H_2 pipelines. But, like for H_2 in the natural gas grid, the new Renewable Energy Directive introduces guarantees of origin for H_2 produced with renewable energy in H_2 pipelines. The ETS is in general applicable and, because in a pure H_2 pipeline there is no concurrence with natural gas, the specific distortions observable for H_2 in the natural gas grid in respect of the ETS are not relevant in this context: The end user does not produce CO_2 emissions anyway and CO_2 emission allowances are only needed

for the (large scale) production of H_2 from fossil fuels, directly competing with a production with renewable energy.

5.2.2.4 Hydrogen Pipeline Regime for Feedstock/General Pipeline Regime

The regime for feedstock pipelines is well established. But as feedstock pipeline networks do not compare to energy network in regard to the scale and the societal relevance, the regulatory density of the general (feedstock) pipeline regime is far less than that of the energy network regimes, mostly aimed at safety and environmental protection issues. For the German case study, this part of the legal landscape is most relevant as the potential fall-back regime against the background of the intense legal uncertainty in regard to H_2 pipelines for energetic purposes.

There is no specific set of general rules for feedstock pipelines on EU law or international public law level. Despite the wording of the Natural Gas Directive which refers to all gases that can be injected into the natural gas grid, the directive is bound to a natural gas context. Pipelines were even explicitly excluded from Directive 2012/18/EU which harmonises major accidents law.

On the national level, there is no specific law for H_2 as feedstock. The scope of the EnWG is confined to energetic purposes. Therefore, general pipeline law pursuant to the UVPG and the RohrFLtgV as well as the general rules of competition, facility and hazardous materials law are applicable.

For construction, a planning decision is required pursuant to § 66 UVPG dependent on the categories of the UVPG for gas pipelines in general (starting at 300 mm). Otherwise, several single permits and procedures are required. Lacking special provisions on federal level, the competent authorities are determined by state law. For a planning decision in NRW, this is the general regional administration. As there is no specific federal law for feedstock pipelines in regard to expropriations, state law is applicable. In North-Rhine Westphalia, § 2 of the Expropriation Act (EEG NW) provides for expropriations of land needed for feedstock pipelines albeit it lacks an accompanying system of rights and powers as in the EnWG and even the constitutionality of this provision is debated – against the background of the recent jurisprudence of the Federal Constitutional Court (BVerfG) on expropriation and legal certainty [HOO17] – due to its rather vague reference to the public good.

In regard to planning, the general rules apply to long-distance pipelines as regionally significant projects. In North-Rhine Westphalia, the rules of the regional planning provisions for pipelines also apply to feedstock H_2 pipelines.

For feedstock H_2 system operators, there are no rules in regard to unbundling and licensing. Access, abuse control and tariffs are governed by the general competition law, especially the essential facility doctrine. There is no specific system responsibility, but the private law obligations and general facility law have to be considered. Accordingly, there is no specific competent authority.

General safety requirements are stipulated in § 66 UVPG and more specific safety regulation, also addressing major accidents, is provided by the RohrFLtgV. Cross-border trade and transport are addressed only by general rules, especially the free movement of goods. Neither is there a specific regime for technical rules or interoperability.

In regard to the integration into existing systems, the same rules as for energy H_2 pipelines apply; although the guarantees of origin pursuant to the Renewable Energy Directive refer to energetic purposes, there are no compelling reasons to bar feedstock H_2 from this scheme as it can always be used as energy carrier anyway.

5.2.2.5 Overview and Comparison

The legal landscapes of the different pipeline regimes vary in legal sources, content, regulatory density and legislative quality. This is due to the different maturity of the subject matter and the different focuses of the regimes: waste law for CO_2, energy law for energy pipelines and facility law for all. Especially the energy H_2 pipelines regime, which is set between the natural gas regime and the feedstock pipeline regime without a clear allocation, raises issues. It is not even certain, if there is a specific energy H_2 pipeline regime, while the differences between the feedstock pipeline regime and the energy natural gas pipeline regime emphasise the relevance of proper allocation. The high degree of legal uncertainty in regard to energy H_2 pipelines also radiate to the other regimes because it also encompasses the boundaries of the regimes: Even assuming a specific energy H_2 pipeline regime, it is not clear at which share of usage a pipeline for feedstock turns into a pipeline for energetic purposes and vice versa while neither it is clear at which share a natural gas pipeline with admixed H_2 turns into an H_2 pipeline with admixed natural gas; the demarcations remain unclear independently from the assumption of a specific energy H_2 pipeline regime.

EU harmonisation law in regard to CO_2 pipelines for CCS is rather restrained and in regard to H_2 pipelines not existing. In sharp contrast, the harmonisation for natural gas networks is massive and extensive. On the international public law level, the focus of the CO_2 pipeline regime on waste law is relevant as constraints by international environmental law have to be considered.

Similarly, the national law is rather restrained in regard to CO_2 pipelines and rather intense in regard to natural gas pipelines while there is no specific regulation for H_2 pipelines. Yet, the national general pipeline and facility law is relevant. In regard to energy H_2 pipelines, a special issues arises from the hybrid structure of German energy law that connects both to EU harmonisation law in regard to natural gas networks and to the comprehensive tradition and claim to cover all energy gas pipelines without – against the actual background of natural gas dominance – reflecting and addressing possible conflicts.

Despite the different legal backgrounds, the actual regulation for the construction of pipelines is largely parallel. The regime for CO_2 pipelines for CCS features an additional duty for public information in advance and proscribes planning decisions without restriction in regard to size; this reflects concerns about public acceptance. In regard to expropriations, there are substantive differences between the feedstock pipeline regime and the other pipeline regimes.

Regional and general planning law apply to all pipelines with differences in details (like the special procedure demanded by the RoV). Substantive differences can be observed in regard to special legal instruments for planning and coordination, which are fully developed only for natural gas networks.

In regard to operator duties, the different focuses on (highly regulated) energy law and (sparsely regulated) facility law are most visible. Even for energy H_2 pipelines – if assumed – in comparison to energy natural gas pipelines, substantive differences have to be considered, especially in regard to unbundling, network access and tariffs regulation, that is specifically designed for natural gas networks. The CO_2 pipeline regime orients towards the energy pipeline regimes in this regard, but is far less regulated.

In regard to safety, the requirements of the different regimes are quite similar. Just for CO_2 pipelines, there are no specific ordinance provisions for major accidents. Whereas the differences in the legal requirements can be rather neglected, the actual legal effects due to the different technical problems can be substantive. Especially in regard to CO_2, the hazards and the dynamics of spreading in the case of a major accidents is so different from those in regard to natural gas and H_2, that – against the background of ongoing research in the matter – an own approach, especially for safety distances and pipeline routing [BUN18], is legally demanded.

Table 5.1: Overview applicable law.

Area of law	Carbon Dioxide	Natural Gas	Hydrogen (Energy)	Hydrogen (Feedstock)
Harmonisation	CCS Directive	Natural Gas Dir.; Transmission Reg.	-	-
Administrative Procedure for Construction	Planning decision, § 4 KSpG + (partly) EnWG/VwVfG	For > 300 mm: planning decision, EnWG/VwVfG; otherwise single procedures	For > 300 mm: planning decision, EnWG/VwVfG; otherwise single procedures	For EIA: planning decision, UVPG/VwVfG; otherwise single procedures
EIA	No. 19.10 in Annex 1 UVPG	No. 19.2 in Annex 1 UVPG	No. 19.2 in Annex 1 UVPG	No. 19.5 in Annex 1 UVPG
Expropriation	§§ 4, 15 KSpG	§ 45 EnWG	§ 45 EnWG	State law (e.g. § 2 EEG NW)
Planning Instruments	Reg. Planning, ROG; TEN-E	Reg. Planning, ROG with special proced.; NDPs (EU/Germ.); TEN-E	Reg. Planning, ROG with special proced.	Reg. Planning, ROG
Unbundling	-	EnWG	-	-
Licensing	-	EnWG + Transmission Reg.	EnWG	-
Comp./Regul. -Access -Tariffs -Abuse Control	§ 33 KSpG; non-discrimination, § 33 KSpG; general comp. law	EnWG; EnWG + ordinances; EnWG	partly EnWG; non-discrimination, EnWG; EnWG	general comp. law
System Resp.	-	EnWG	EnWG (largely)	-
Safety	§ 4 KSpG + § 49 EnWG	§ 49 EnWG + GasHDrLtgV (incl. major accidents)	§ 49 EnWG + GasHDrLtgV (incl. major accidents)	UVPG + RohrFLtgV (incl. major accidents)
Cross-Border Trade	KSpG; free movement of goods; London Protocol	Transm. Reg. + network codes; free movement of goods	free movement of goods	free movement of goods
Technical Rules	non-discrimination, § 33 KSpG	Technical rules of operators, EnWG; interop., EnWG; network codes + Transmission Reg.	Technical rules of operators, EnWG; interop., EnWG	-
Integration into system	ETS	ETS; biogas mechanism, EnWG; guarantees of origin, Renew. Energy Dir.	ETS guarantees of origin, Renew. Energy Dir.	ETS guarantees of origin, Renew. Energy Dir.
Competent Authority	Constr.: state law; comp./reg.: BNetzA; safety: state law	Constr.: state law comp./reg.: BNetzA/ state reg. auth. syst. resp.: BNetzA/ state reg. auth. safety: state law	Constr.: state law comp./reg.: BNetzA/ state reg. auth. syst. resp.: BNetzA/ state reg. auth. safety: state law	Constr.: state law safety: state law

In respect of cross-border trade and transport, the regimes for CO_2, natural gas and H_2 differ greatly. While H_2 is governed by general internal market law, natural gas is subject to extensive regulation to promote cross-border trade and transport in the internal market. On the other hand, the cross-border trade and transport of CO_2 are rather affected by constraints despite a favourable, yet sparse regulation.
The legal landscape in regard to technical rules and interoperability connects to this picture: Only general internal market law applies to H_2 pipelines; natural gas pipelines are heavily regulated; for CO_2 pipelines there is no further specification.
The integration of the different regimes into the existing schemes like certificates and ETS shows some deficiencies of these schemes. Formally, the ETS covers all relevant aspects of CCS and H_2 production. But it is unable to process the special interactions of natural gas, H_2 and CO_2 in an H_2-CCS chain in a coherent way, especially in regard to H_2 in natural gas networks. The new Renewable Energy Directive introduces an open general scheme for guarantees of origin, that will fully integrate H_2 into this system, but does not cover other means to mitigate CO_2 emissions such as CCS.

5.2.3 Details in Regard to Pipeline Size

In regard to different aspects, the pipeline regimes refer to the size of the pipelines. Thus, the legal landscape is also shaped by pipeline characteristics in respect of size.

Table 5.2: Overview Pipeline Size and Legal Regime.

<table>
<tr><th>Size of the Pipeline</th><th>Carbon Dioxide</th><th>Natural Gas</th><th>Hydrogen (Energy)</th><th>Hydrogen (Feedstock)</th></tr>
<tr><td><150 mm</td><td>planning decision</td><td rowspan="2">-</td><td rowspan="2">-</td><td rowspan="2">-</td></tr>
<tr><td>150 mm to 300 mm</td><td rowspan="2">planning decision
preliminary assessm.
• site related for <2 km
• general for >2 km</td></tr>
<tr><td>300 mm to 800 mm</td><td>planning decision
preliminary assessm.
• site related for <5 km
• general for >5 km
RoV-procedure</td><td>planning decision
preliminary assessm.
• site related for <5 km
• general for >5 km
RoV-procedure</td><td>planning decision
preliminary assessm.
• site related for <5 km
• general for >5 km</td></tr>
<tr><td>>800 mm
<2 km</td><td>planning decision
preliminary assessm.
(site related)</td><td rowspan="2">planning decision
preliminary assessm.
(site related)
RoV-procedure</td><td rowspan="2">planning decision
preliminary assessm.
(site related)
RoV-procedure</td><td rowspan="2">planning decision
preliminary assessm.
(site related)</td></tr>
<tr><td>>800 mm
2 km to 5 km</td><td rowspan="2">planning decision
preliminary assessm.
(general)</td></tr>
<tr><td>>800 mm
5 km to 40 km</td><td>planning decision
preliminary assessm.
(general)
RoV-procedure</td><td>planning decision
preliminary assessm.
(general)
RoV-procedure</td><td>planning decision
preliminary assessm.
(general)</td></tr>
<tr><td>>800 mm
>40 km</td><td>planning decision
EIA</td><td>planning decision
EIA
RoV-procedure</td><td>planning decision
EIA
RoV-procedure</td><td>planning decision
EIA</td></tr>
</table>

Especially the UVPG introduces different categories for pipeline sizes. These categories refer to diameter and length of the pipeline and determine if an EIA is necessary or if a general or just site related preliminary assessment has to be conducted to figure out on a case-by-case basis if an EIA is actually needed. Additionally, parallel to the UVPG threshold, the diameter determines the

activation of a procedure for a planning decision. While for CO_2 all pipelines are subject to a planning decision and for other pipelines (like feedstock H_2) the need of a preliminary assessment also triggers a planning decision, energy pipelines with a diameter of more than 300 mm are subject to the special planning decision procedure. This threshold is mirrored in the RoV, which stipulates that for energy pipelines with a diameter of more than 300 mm the special procedure to ensure the compatibility with regional planning pursuant to the ROG is due.
In respect of pipeline size, there are no specific natural gas rules; thus, the size categories are equal for all energy pipelines.
Moreover, the special safety rules and especially the provisions for major accidents pursuant to the corresponding ordinances are addressed at certain pressures. For energy pipelines, the GasHDrV is applicable only to pipelines with a high pressure of more than 16 bar. For other pipelines, the RohrFLtgV is applicable to pipelines with a positive pressure of more than 1 bar.

5.2.4 Conclusions

Three base pipeline regimes are relevant for the legal landscape: CO_2 pipelines for CCS are largely regulated in the KSpG, energy natural gas pipelines are largely regulated in the EnWG and accompanying ordinances and feedstock H_2 pipelines are governed by general competition and facility law and some general rules for pipelines pursuant to the UVPG. In this base landscape, the regime for energy H_2 energy pipelines is hard to allocate and accompanied by intense legal uncertainty. It shares goals and conflicts with the natural gas pipeline regime in regard to energy supply but does not touch other specific issues. Especially, the EU legislation and most of its national implementation are aimed at natural gas and its special market. Thus, the energy H_2 pipeline regime is a hybrid in between the energy pipeline regime of the EnWG and the general regime, which is applicable to feedstock H_2 pipelines.
The legal landscape of the relevant pipeline regimes is influenced by the regulatory goals. Safety and regional conflicts are relevant for all pipeline regimes. Thus, the legal landscape in regard to general planning, safety and construction looks rather uniform for the different regimes, with only a few but marked discrepancies. Yet, even in this regard, the landscape looks rather confusing, due to tendencies to assemble different aspects of specific pipeline regimes within a single act and to partly refer in between different acts. In respect to the specific goals of the pipeline regimes, the differences are much stronger, such as in regard to waste law for CO_2 pipelines, in regard to operator duties and system responsibility for energy pipelines or in regard to market regulation and cross-border coordination for natural gas.
Additionally, differences in regard to regulatory density and quality shape the legal landscape. The regulation for CO_2 pipelines is rather rudimentary. This mirrors the lack of maturity and corresponding experience as well as the absence of mind of the legislator in regard to CO_2 transport. Whereas the legislator for CCS focused rather on storage than on transport, the German legislator has not cared much about CCS as a whole lately. Natural gas and natural gas pipelines are subject to an intense legal and political debate, of high economic relevance and therefore highly regulated in almost every sense. Feedstock pipelines are subject to a mature but rather restrained legislation. The pipeline regime for H_2 for energetic purposes suffers from the fact, that energy H_2 pipelines are neither existing nor much debated. It partly participates in the differentiated regime for natural gas pipelines and partly lacks any specific regulation, always displaying legal uncertainty.

5.3 References

[BUN18] BUNDESREGIERUNG: *Evaluierungsbericht der Bundesregierung über die Anwendung des Kohlendioxid-Speichergesetzes sowie die Erfahrungen zur*

CCS-Technologie. Unterrichtung durch die Bundesregierung. Bundestags Drucksache 19/6891. – URL: http://dipbt.bundestag.de/doc/btd/19/068/1906891.pdf. 2018

[DIX15] DIXON, T.; MCCOY, S. T.; HAVERCROFT, I.: *Legal and Regulatory Developments on CCS*. In: *International Journal of Greenhouse Gas Control* 40, pp. 431–448. 2015.

[FLE18] FLEMING, R.; FERSHEE, J.: *The 'Hydrogen Economy' in the United States and the European Union. Regulating Innovation to Combat Climate Change*. In: Donald Zillman, Martha Roggenkamp, Leroy Paddock, Lee Godden (eds.): Innovation in Energy Law and Technology. Dynamic Solutions for Energy Transitions. Oxford: Oxford University Press, pp. 137–153. 2018.

[HOO17] HOOPS, B.: *Verabschiedet sich das BVerfG von „Boxberg" und seinem international vorbildlichen Schutz vor Enteignungen zugunsten Privater?* In: *Neue Zeitschrift für Verwaltungsrecht* 36, pp. 1496–1500. 2017.

6 SOCIOLOGICAL PERSPECTIVE

Since energy technologies – such as large-scale infrastructure projects or perceived risk technologies – evoke conflicts and protests in the population, acceptance is a key factor for the successful implementation of new technologies. Therefore, the contribution of the current study is to analyse the acceptance of a comprehensive decarbonisation infrastructure via H_2-CCS chains shown in the three options of the German case study. Aspects which are relevant for social acceptance or which have an impact on social acceptance in the German case study are the technology in general, its infrastructural consequences as well as the consumer's acceptance of H_2 as a new energy carrier.

In a first step, the current state of acceptance research on CCS and H_2 technologies as well as on pipeline infrastructure in general was reviewed. In a second step, a systematisation of acceptance was developed as conceptual basis of the analysis (see D5.5.1). To empirically examine social acceptance, a mixed-methods-design is applied. Primarily, explorative interviews were conducted with relevant stakeholders that are located at intersections between politics, economy/industry and society. In these interviews, attitudes, interests and motivations as well as knowledge and experience regarding social perception are reflected from different perspectives. It is assumed that these positions represent the public acceptance discourse with the associated conflict lines and that the stakeholders themselves are highly relevant for the political decision-making. Several stakeholders can be seen as multiplicators which are crucial for the formation and progress of social debates on external technologies. [REN97] Accordingly, the interviews enable to reflect chances and risks for the implementation of energy technology and infrastructure. In the following, the evaluation of the infrastructure options from the experts' perspectives is analysed and preliminary results of the stakeholder interviews are presented.

6.1 Methodology

Stakeholder interviews (N=10) were conducted with relevant stakeholders that are located at intersections between politics, economy/industry and society (see fig. 6.1). The interviews were guided and included following topics:

- Evaluation of technologies/ options in the German case study
- Experience with and evaluation of technology acceptance in society
- Experience with public participation during the planning process
- Information and communication needed to evaluate the options in the German case study

The interviewed stakeholders were assured of anonymity. The interviews were transcribed and analysed using the method of thematic coding. Based on theoretical considerations, categories are developed which are further differentiated and adapted during the analysis. [HOP95] The categories included the stakeholders' evaluation of the options, their knowledge and experience related to the options, their experience with social acceptance of energy technologies and large-scale infrastructure and the stakeholders' perspective towards public participation and communication/information.

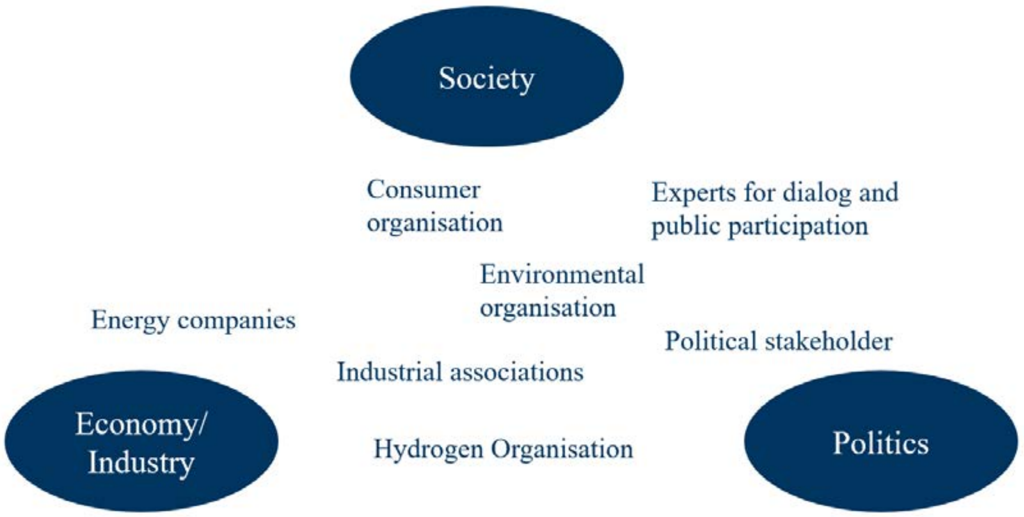

Figure 6.1: Interviewed Stakeholders (N=10).

6.2 First Results

The interviews provide insights about the stakeholders' perspective of the options in the German case study. The aim of the following analysis is to portray the stakeholders' perspective focusing on their evaluation of social acceptance.

The interviewed stakeholders were experts in the field of energy technologies with a focus on CCS technologies and/or H_2 technologies or in the field of social acceptance with a focus on energy technologies and/or large-scale infrastructures. Therefore, the options were viewed from different perspectives.

6.2.1 Overview

The results indicate different positions and assumptions of the stakeholders while pursuing the common goal of addressing climate change. The general conflict concerns the strategy towards a low-carbon society, especially how quickly fossil energies are phased out. Argumentations behind these positions refer among others to security of supply versus environmental protection, different assumptions on dealing with societal demand and needs for energy as well as aspects regarding centralisation and decentralisation of the energy system. Alongside opposing and conflicting arguments within and between social areas, also intersecting sets are emerging, for example concerning the decarbonisation of industry.

During the interviews, the stakeholders named challenges and risks as well as opportunities and strengths of the options. Some recurring lines of argumentation became apparent:

- Social acceptance was one of the main challenges recognised by all stakeholders. In transferring their experience to the options, main challenges in terms of social acceptance have been seen in the requirement of new infrastructure, in the lack of social acceptance of CCS technologies and in the perception of H_2 and CCS as risk technologies.
- Another main challenge in the opinion of the interviewed stakeholders is the economic feasibility of the options. New large-scale infrastructure and the implementation of new technologies require high investments. At the same time, energy supply has to be affordable. Therefore, the issue of cost distribution needs to be addressed.

- This aspect is closely related to political and legal uncertainty, stated by some stakeholders. From their perspective, a legal and political framework is needed to invest in the development and expansion of technologies and energy infrastructure.
- Ecological consequences of the options and sustainability concerns are mostly thematised by the environmental organisation. Furthermore, ecological consequences are recognised as one central factor for social acceptance.
- All stakeholders acknowledged the general potential of reducing CO_2 emissions as opportunity and strength of the options, albeit to varying degrees. While there are controversial perceptions of the benefit to decarbonise fossil energies via CCS, the benefit of decarbonising industry-induced or bioenergy-induced emissions was rather met with approval. In this context, several stakeholders issued effects of carbon leakage – the relocation of industry to countries with lower emission requirements and thus an overall increase in emissions.
- The technological feasibility of the options is mainly evaluated positive by the stakeholders with technological expertise. Technological challenges played a rather minor role compared to other challenges.
- Finally, using existing infrastructure was pointed out to be an important aspect which also affects the previous aspects. Especially social acceptance and economic feasibility are assumed to be positively affected by using existing infrastructure.

The relevance and prioritisation of the challenges – economic feasibility, legal/political feasibility or social acceptance – differed between stakeholders.

6.2.2 Social Acceptance from Stakeholders' Perspective

Social acceptance of the options from the stakeholders' perspective was analysed on the basis of the systematisation of acceptance. This approach enables to differ three levels of acceptance which address different levels of abstraction and different areas of acceptance. [HIL18; SCH17; LOR14; HUI12; ZOE12]

The first level is about the general acceptance of decarbonisation by H_2 technologies and CCS as part of the energy transition. The second level is about the acceptance of the implementation and its consequences. The third level concerns the acceptance of the planning process of the implementation and the acceptance of relevant stakeholders – like perceived fairness of the planning process and trust in stakeholders.

6.2.2.1 Acceptance of Decarbonisation by H_2-CCS Chains as Part of the Energy Transition

On the general level of acceptance of H_2-CCS chains to decarbonise the energy system, stakeholders expect a lack of acceptance. The reason for this evaluation lies in the CCS part of the chain and its combination with fossil energy carriers. CCS technologies are expected to be perceived as stabilising fossil energy carriers while competing with the expansion of renewable energy carriers. In this context, CCS to decarbonise industry-induced emissions is assumed to be more accepted than CCS to decarbonise fossil energy-induced emissions.

Although the H_2 part of the chain is assumed to be more accepted than the CCS part, the type of H_2 is assessed to be relevant for acceptance. Green hydrogen is supposed to be more accepted than blue or conventional hydrogen, because on a general level – as most stakeholders pointed out – renewable energies experience the highest acceptance of energy technologies in Germany.

The stakeholders evaluate public knowledge about CCS and H_2 technologies as rather low. Knowledge about H_2 technology in the society is assessed to be low due to its low market penetration and absence in the everyday life of consumers. Nevertheless, it is assessed that many have heard of it before and have a rough idea about it. The technology is marginally discussed in public, mostly within the context of mobility. On the political level, H_2 technologies are discussed, but are competing with electrical applications. CCS technologies are assessed not to be present in current public discussions. But according to several stakeholders, it is just becoming more present again in political discussions. In this context, some stakeholders referred to the position paper drafted by the National Academy of Science and Engineering (acatech) in 2018 on CCS and CCU in industry to address climate mitigation. The aim of the paper was to foster the resumption of the technologies in political discussions [ACA18].

Several stakeholders draw attentions to contradictions that – from their perspective – are present in society. These concern consistent demand for energy, absence of acceptance for fossil energy carriers and technologies and at the same time a lack of acceptance for infrastructural consequences of renewable energies.

6.2.2.2 Acceptance of the Implementation and its Consequences

On the level of implementation and consequences of an H_2-CCS chain, stakeholders mainly referred to risk perception of the technologies and infrastructural consequences. Several stakeholders referred to previous CCS projects, especially on-shore CO_2 storage in Germany, that have been rejected. The first main aspect for the rejections was its perception as hazard sources due to possible leaks and seismic risks. Risk perception of CO_2 capture and transport is assumed to be lower, but still present. Also, H_2 fuel stations have not raised major concerns yet. In general, stakeholders noticed that social perception of storage technologies is rather positive because of their relevance to renewable energies. In contrast to natural gas storage sites, which partly are associated with high risks for residents and environment, H_2 storage sites and electrolysers have not raised acceptance problems thus far. However, this could also be due to the fact that currently, H_2 storage sites do not have the same dimensions as natural gas storage sites. The expected acceptance of H_2 technologies is different between the stakeholders due to different assumptions regarding public risk perception of H_2. One stakeholder describes rather positive feedback and open-mindedness about H_2 as energy carrier in the mobility sector. Reservations regarding the technology are more related to aspects of technology reliability and availability at acceptable costs than about risks and safety. Other stakeholders expect a high level of risk perception because it is perceived as highly explosive substance and therefore risky in its application.

The second main aspect regarding acceptance of H_2-CCS chains is seen in the degree of adaptation of infrastructural consequences. In this context, especially new pipeline infrastructure was assumed not to be accepted and to cause NIMBY effects as well as concerns about landscape and environmental protection. All stakeholders think that avoiding new large-scale infrastructure and using existing infrastructure is very relevant to increase acceptance. Nevertheless, some stakeholders indicate that using existing infrastructure is not automatically increasing acceptance: If new risks are associated with infrastructural retrofitting and modification, acceptance will be just as low. Several stakeholders draw comparisons between pipeline construction to transport CO_2 respectively H_2 and power line construction. Referring to the rejection of power lines construction in large parts of Germany, same trends are expected regarding the construction of a CO_2 or H_2 pipeline. Furthermore, several stakeholders expect a mix up of CO_2 or H_2 pipelines with the constructed but not operating CO pipeline of Bayer AG in North Rhine-Westphalia in 2009. They pointed out that the pipeline evoked strong protests in the local population, mainly due to high risk perception. Transport via ship and/or lorry are assumed to be more accepted and suggested as possible alternatives.

Although CO_2 capture is assessed as less relevant for social acceptance, some differences of the capture technologies were remarked: In contrast to oxyfuel technology, post combustion capture takes larger construction works and brings a visible and significant change of the existing plant. Therefore, acceptance-relevant aspects may occur because of construction sites and changes in the landscape.

6.2.2.3 Acceptance of Procedures and Relevant Stakeholders

It is recognised that trust and credibility in stakeholders is essential for public acceptance. Thereby, some stakeholder groups are more trusted by the population than others. These are especially (environmental) NGOs and local stakeholders, for example local politicians and local investors who are attributed to represent local and civic interests. In contrast, non-local stakeholders and large (energy) companies are less trusted due to a lack of this attribution.

Next to project or technology acceptance, the importance of acceptance of the planning process is emphasised by one expert. Which stakeholders are part of the planning process and if there is a possibility for public participation is assumed to have crucial impact on its acceptance. At the same time, the interviewed stakeholders have controversial perceptions of public participation in planning processes. Some experience public participation as rather helpful and necessary for the implementation of large-scale infrastructure projects, some do not.

6.3 Conclusion and Prospect

The stakeholder interviews indicate controversial as well as consensual perceptions of the German case study options. The assessments range from rejection of an H_2-CCS chain to deeming it absolutely necessary. In addition to conflicting and contradictory arguments within and between politics, economy/industry and society, there are also consensual perceptions in the evaluation of the options. These indicate chances to approach solutions for broad stakeholder acceptance which are assumed to represent the social acceptance discourse.

The interviews clarify aspects of social acceptance regarding the options. The results mostly confirm the current state of research on CCS, H_2 technologies and large-scale infrastructure. In addition, new insights provide specifications in regard to the framework of the options. Several principal assumptions are derived from this:

- Energy carriers like H_2 or natural gas-hydrogen-composites are perceived more beneficial than CO_2. Therefore, pipelines transporting energy carriers like H_2 or natural gas-hydrogen-composites are more accepted than CO_2 pipelines.
- The acceptance of H_2-CCS chains is higher if they are perceived complementary rather than competing to the expansion of renewable energy technologies.
- Green hydrogen is perceived more positively than blue hydrogen. H_2 storage sites are more accepted, if part of the stored H_2 is produced from renewable energies.
- The further away the storage of CO_2 is from one's own place of residence, the higher is the acceptance. CO_2 storage outside of Germany is more accepted than CO_2 storage inside Germany.
- Within an H_2-CCS chain, risk perception of CCS technologies is higher, than risk perception of H_2 technologies.
- CCS to decarbonise industry is perceived more positively than CCS to decarbonise fossil energies.
- The acceptance of the implementation is higher, if it is based on existing infrastructure.
- The acceptance of H_2-CCS chains is lower among more environmentally conscious people than among less environmentally conscious people.

In a next step, representative data will be gathered by a quantitative online survey of public acceptance in the German population (N≈1,000). Thereby, hypotheses deduced from the current state of research and the stakeholder interviews will be tested. The little knowledge and awareness of the technologies in the population is a challenging factor which will be responded to via informed polling, following the ICQ method [TER13]. Attitudes and acceptance towards the options will be measured, providing adequate information to conceive well-considered and well-informed opinions.

The combination of the explorative study with the deductive hypotheses testing study results in a holistic portrait of social acceptance regarding H_2-CCS chain options in Germany. This allows to better understand the factors that affect social acceptance and to recognise risks and opportunities during the process of decarbonising the energy system.

6.4 References

[ACA18] ACATECH – DEUTSCHE AKADEMIE DER TECHNIKWISSENSCHAFTEN (ED.): *CCU und CCS – Bausteine für den Klimaschutz in der Industrie. Analyse, Handlungsoptionen und Empfehlungen*. – URL: https://www.acatech.de/wp-content/uploads/2018/09/acatech_POSITION_CCU_CCS_WEB-002_final.pdf. 2018.

[HIL18] HILDEBRAND, J.; RAU, I.; SCHWEIZER-RIES, P.: *Akzeptanz und Beteiligung – ein ungleiches Paar*. In: Lars Holstenkamp und Jörg Radtke (eds.): Handbuch Energiewende und Partizipation. Wiesbaden: Springer Fachmedien, pp. 193–209. 2018.

[HOP95] HOPF, C.; RIEKER, P.; SANDEN-MARCUS, M. ET AL.: *Familie und Rechtsextremismus. Familiale Sozialisation und rechtsextreme Orientierungen junger Männer*. Weinheim: Juventa Verlag. 1995.

[HUI12] HUIJTS, N.; MOLIN, E.; STEG, L.: *Psychological factors influencing sustainable energy technology acceptance. A review-based comprehensive framework*. In: *Renewable and Sustainable Energy Reviews* 16, pp. 525–531. 2012.

[LOR14] L'ORANGE SEIGO, S.; DOHLE, S.; SIEGRIST, M.: *Public perception of carbon capture and storage (CCS). A review*. In: *Renewable and Sustainable Energy Reviews* 38, pp. 848–863. 2014.

[REN97] RENN, O.; ZWICK, M. M.: *Risiko- und Technikakzeptanz*. Berlin u.a.: Springer. 1997.

[SCH17] SCHÖNAUER, A.-L.: *Industriefeindlichkeit in Deutschland. Eine empirische Analyse aus sozialwissenschaftlicher Perspektive*. Wiesbaden: Springer Fachmedien. 2016.

[TER13] TER MORS, E.; TERWEL, B. W.; DAAMEN, D. D.L. ET AL.: *A comparison of techniques used to collect informed public opinions about CCS. Opinion quality after focus group discussions versus information-choice questionnaires*. In: *International Journal of Greenhouse Gas Control* 18, pp. 256–263. 2013.

[ZOE12] ZOELLNER, J.; SCHWEIZER-RIES, P.; RAU, I.: *Akzeptanz Erneuerbarer Energien*. In: Thorsten Müller (ed.): 20 Jahre Recht der Erneuerbaren Energien, 1st ed. (Online-ed.). Baden-Baden: Nomos Verlag, pp. 91–107. 2012.