Emerging business model designs for the hydrogen economy: An explorative enquiry into the German IPCEI* projects

*Important projects of common European interest

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Kerstin Gemmer-Berkbilek

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Abstract

"Water is the coal of the future. The energy of tomorrow is water, which has been broken down by electric current."

Jules Verne in "The Mysterious Island", 1874

The Paris Agreement's climate goals and the sustainable development goals of the UN have spurred efforts to decarbonise industry in Germany and Europe, with hydrogen (H_2) emerging as a key future energy source. Despite publicly funded programmes to boost the hydrogen economy, the implementation of large-scale hydrogen projects is lagging behind expectations. Advanced business model designs might be a means to facilitate market ramp-up.

A systematic review of existing literature revealed that no published work on business models or designs for green hydrogen projects is available. This study conducts an exploratory enquiry into the German IPCEI[1] hydrogen projects to investigate and better understand business modelling for the H_2 economy. The study was designed as a case study using various sources, including a survey, 16 semi-structured interviews with project actors and other stakeholders, several conference contributions and various documents. The data was analysed by employing reflexive thematic analysis (Braun & Clarke, 2006).

Casting light on the current business logic shaping business models in the hydrogen economy, this study reveals key outcomes:

1. Uncovering a multitude of design elements, categorised in - 10 dimensions, 43 parameters, and over 50 design choices - available for crafting robust business models.
2. Identifying 18 influencing factors categorized as input or output variables, including insight on their impact on the business model.
3. Emphasising the importance of assessing feasibility AND viability to ensure that the business is executable. Today only business models that do not require an existing H_2 infrastructure for large scale H_2 transport and H_2 storage are feasible.

By providing conceptual models and a practical guide, this study equips businesses with actionable insights for navigating the dynamic hydrogen economy and making informed decisions when designing their business models. Bridging gaps in existing literature and enhancing Osterwalder, Pigneur, and Tucci's (2005) hierarchical model with external macroeconomic factors and an industry-specific taxonomy, this study significantly advances academic understanding in the field.

[1] IPCEI – Important Projects of Common European Interest

Author's Declaration

I declare that the work in this assessment was carried out following the regulations of the University of Gloucestershire and is original except where indicated by specific reference in the text. No part of the thesis has been submitted as part of any other academic award. The thesis has not been presented to any other educational institution in the United Kingdom or overseas.

Any views expressed in this assessment are those of the author and in no way represent those of the University.

Signed: [redacted]

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Abbreviations

BM	business model
BMI	business model innovation
CAPEX	capital expenditures
CCS	carbon capture and storage
CH_4	methane
CIMO	context - intervention – mechanism - outcome
EU	European Union
EUR	Euro (€)
FID	final investment decision
GHG	greenhouse gas emissions
GW	Gigawatt
H_2	hydrogen
H_2O	water
ID	identifier
IPCEI	Important Projects of Common European Interest
JV	joint venture
MW	Megawatt
O_2	oxygen
OPEX	operational expenditures

PPA	power purchase agreement
PtG	Power-to-Gas
PtX	Power-to-X (X stands for various products to be produced from power (electricity))
R&D	research & development
RQ	research question
SDGs	sustainable development goals
SLR	systematic literature review
SPV	special purpose vehicle
TSO	transmission system operator
USD	US Dollar ($)
VUCA	Volatility – Uncertainty – Complexity - Ambiguity
WoS	Web of Science

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Part 1 Introduction, literature review, philosophical background and the research design

1. Introduction and Problem Statement

1.1. Introduction to the chapter

This chapter introduces the research. It sets out the background, that is, energy transition and the context, that is, the role of hydrogen, in which the study is nested. Then, the motivation for the study is presented, which is the mismatch between the published plans for the ramp-up of the hydrogen economy and the actual degree of implementation. The underlying proposition that adequate business models could facilitate the ramp-up is presented next, together with the aim of the research and the perspective adopted on the study topic. Then, the setting in which the study is taking place is outlined; these are the IPCEI hydrogen projects in Germany, the related research objectives are introduced, and the scope is framed. The next section explains the most relevant technical contexts for understanding the study, i.e., the value chain and the colours of hydrogen. The chapter concludes with the presentation of the structure of the remaining thesis.

1.2. The role of hydrogen in energy transition - context and background

The global commitment to combat climate change, as outlined in landmark agreements like the Paris Agreement (UN, 2015) and echoed in initiatives such as the EU's aim for climate neutrality by 2050 (e.g. 2023; EC, 2023d), has ignited a decisive shift away from reliance on fossil fuels. Central to this transition is recognising green hydrogen (H_2) as a pivotal player in reshaping the energy landscape. The integration of green hydrogen projects also aligns with the United Nations Sustainable Development Goals (SDGs), in particular with goal 7 (affordable energy) and goal 13 (climate action) by promoting clean energy production, reducing carbon emissions, and fostering sustainable economic growth (UN, 2016).

The versatility of green hydrogen as both an energy carrier and a vital component for industrial processes positions it as a linchpin in the journey towards sustainability, as illustrated in Figure 1. Moving from left to right, this graphic delineates the multifaceted role of hydrogen within the energy ecosystem. Roles 1 to 3 elucidate the integration of hydrogen production technologies into the electricity system, often referred to as Power-to-Gas (PtG) applications. Meanwhile, roles 4 to 7 underscore the diverse applications for hydrogen, ranging from fuelling vehicles to serving as a cornerstone for industrial processes like steel manufacturing. Ultimately, hydrogen stands poised to supplant traditional energy sources, including natural gas, particularly in sectors like building heating, thereby advancing the collective pursuit of a greener future.

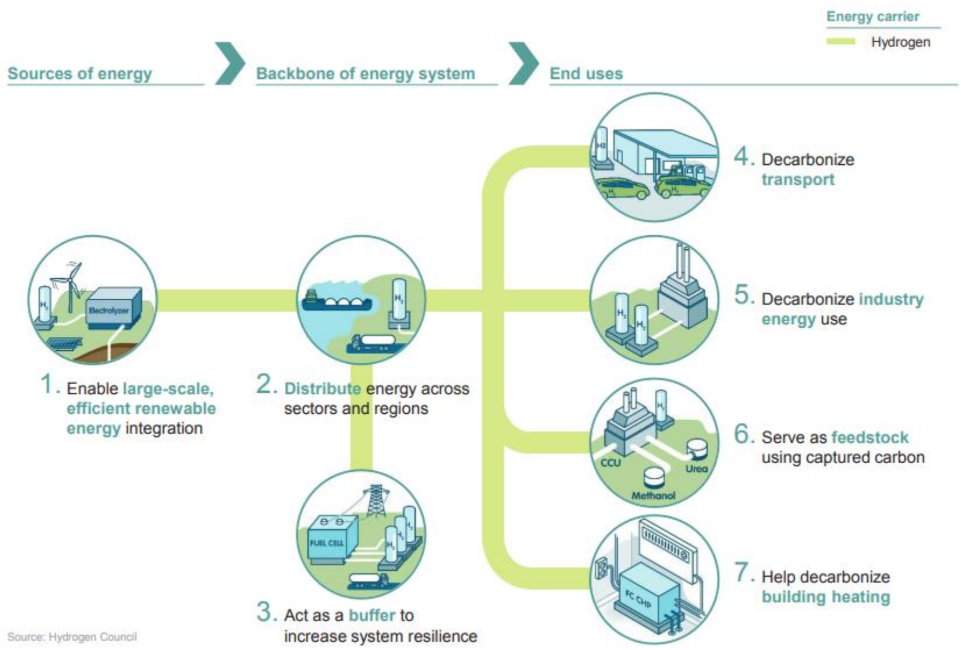

Figure 1 The seven roles of hydrogen in decarbonising major sectors of energy (Hydrogen Council, 2017, Figure 2)

The future role of hydrogen is also manifested in the various hydrogen strategies that 41 governments worldwide have in place (IEA, 2023a, p. 14).

Russia's military attack on Ukraine in February 2022 seems to mark a fundamental paradigm shift in German and European security, energy and industrial policy. In response, the EU announced the REPowerEU Plan (EC, 2022b) that supports measures to diversify the energy supply and accelerate the transition of the energy system towards fossil-free energy sources to become independent from Russian oil and gas imports. In light of the energy crisis in Europe caused by the war, the role of green hydrogen in the energy system appears to be becoming much more important for Europe and Germany. This is evident in the update of the National Hydrogen Strategy (BMWK, 2023c) published in July 2023. In addition to climate protection reasons, the strategy update now prioritises the security of H_2 supply, domestic H_2 production and diversification and security of international H_2 imports. These goals were barely mentioned in the first edition of the strategy in 2020 (BMWK, 2020).

The rationale for this study stems from the increasing global focus on transitioning towards sustainable and decarbonized energy sources, with hydrogen emerging as a key player in this transition. This study focuses on Germany as Europe's largest economy and a leader in renewable energy adoption. This study also focuses on Germany because of Germany’s strong political commitment to decarbonisation and ambitious climate goals. The study recognises the potential political and economic importance for Germany’s economy in investing in future technology development, such as electrolysers and hydrogen infrastructure. This undoubtedly requires major investments, but also potentially ensures a leading role in the technologies of the future.

1.3. The motivation, rationale, and aim of the study

The practical problem observed in 2020, at the beginning of the study, was the observation that there was an obvious gap between the hydrogen projects announced to be built and the hydrogen projects that were being built. Working in the hydrogen business, the author of this thesis was personally affected by delayed and cancelled hydrogen projects. Sometimes, the actors invested great efforts in planning and project development into projects that have been cancelled in the end (e.g. the “Westküste100” - electrolyser project in Northern Germany (Westküste, 2023)).

In 2023, the author's first hand encounter with the sluggish pace of hydrogen project implementation was underscored by corroborating evidence from publicly available sources. For instance, according to H. C. McKinsey's findings (2023), globally, less than 10% of the projects have advanced to the final investment decision (FID) stage despite a notable surge in the hydrogen project pipeline. The situation is even more stark in Europe, with a mere 4% of announced investments receiving positive decisions as of 2023. Echoing these concerns, the IEA (2023a) critiques the struggle to translate the momentum surrounding hydrogen into tangible deployment. The agency stresses that to align with the EU's net zero plans, hydrogen deployment needs to grow more than 100-fold by 2030 (IEA, 2023a, p.14). While these reports address the challenges, they do not delve deeply into the underlying reasons for the lagging investments. Factors such as cost escalations, elevated project risks, and regulatory hurdles are mentioned as potential contributors but are not thoroughly explored. As for recommendations to expedite the ramp-up, the papers offer general guidance, advocating for robust international cooperation and closer collaboration between industry and governments. However, they do not provide detailed strategies for overcoming the identified obstacles.

The underlying proposition that appropriate business models can help the implementation of projects was inspired by the famous examples where a change in the business model design has changed the whole business and created new business cases. Some widely discussed cases in business model literature are the Xerox example (Chesbrough & Rosenbloom, 2002) and Ryan Air case (Casadesus-Masanell & Ricart, 2010).

The identified practical problem and the underlying proposition form the motivation and rationale for this study.

The aim of the study is:

To investigate and understand business modelling for the H_2 economy

Whether a project is realised or not is mostly decided by the relevant project actors, such as the management board of the investing companies or the operating company; in other words, those in charge of the FID. So, these actors can probably best tell what their envisaged business model for the project is, what is needed, what is missing, and what their hurdles and drivers for implementing the project are. This was the main reason for investigating the topic from the actors' perspective.

The choice to approach the topic through the lens of the actors involved necessitates enquiring into tangible projects. The upcoming chapter unfolds the selection process behind focusing on the German IPCEI projects and their associated stakeholder groups as the focal point of this study.

1.4. The setting of the study, the scope and the research objectives

In 2021, 62 large-scale hydrogen projects have been pre-selected by the German government to be notified for European IPCEI funding (EC, 2022a). These projects trigger an investment of 33 billion euros in Germany, and their successful implementation plays a major role in the hydrogen market ramp-up in Germany, as stated in the update of the National Hydrogen Strategy (BMWK, 2023c).

The German IPCEI hydrogen projects stand out as the focal point for this case study due to their significance and uniformity in undergoing approval processes, thus providing a solid foundation for comparison. Encompassing the entire value chain of the hydrogen market, these projects span H_2 production, infrastructure, industry, and mobility sectors. In the initial phase, phase 1, which involved screening, all IPCEI projects were under consideration. However, in phase 2, the primary focus shifted towards H_2 generation and infrastructure projects. These particular projects were chosen due to their complexity, making them compelling subjects for study, and due to their accessibility.

Derived from the case setting, the IPCEI projects, and from scholarly business model descriptions and definitions (e.g. Casadesus-Masanell & Ricart, 2010; Osterwalder, Pigneur, & Tucci, 2005; Zott & Amit, 2010) in total, four objectives were formulated, that should help to achieve the overall aim, that is ***to investigate and understand business modelling for the* H_2 *economy*:**

Objective 0: To critically assess the implementation status of the German IPCEI projects

Objective 1: To collect and critically evaluate the elements that compose future business models

Objective 2: To critically explore the interaction and relationships of those elements

Objective 3: To critically investigate the business model designs that are currently discussed

Objective 0 was mainly addressed during Phase 1, and objectives 1 to 3 were mainly addressed during phase 2 of the study.

The next section introduces the key terminology and related background information used in this study.

1.5. The colours of hydrogen and the hydrogen economy value chain

What is green hydrogen?

Chemically speaking, hydrogen is an invisible, colourless gas. Nevertheless, depending on its production method, the energy industry has assigned colour names to the hydrogen. The relevant hydrogen type for this study is the so-called "green hydrogen". Green hydrogen is produced by an electrochemical process called water electrolysis. Large electrolysers use electricity from renewable sources (e.g., wind and solar power) to split water (H_2O) into its chemical components, hydrogen (H_2) and oxygen (O_2). Because renewable electricity is used, this process has no direct emissions. This is why it is called green hydrogen.

Grey hydrogen is produced from the methane (CH_4) in natural gas, e.g. by steam reforming; this is today the most commonly used form and the most emission-intensive form of hydrogen. A relevant part of the hydrogen industry ramp-up relates to substituting grey hydrogen for green hydrogen to reduce carbon emissions.

The final type of hydrogen to consider for this study is known as blue hydrogen. Produced similarly to grey hydrogen, blue hydrogen incorporates carbon capture and storage (CCS) technology into its production process. While it is important to note that blue hydrogen is not entirely emission-free, certain countries are inclined towards its adoption as a transitional solution. This approach serves as a bridge technology until green hydrogen becomes more economically viable, facilitating the rapid expansion of the hydrogen industry (Deloitte, 2023).

Other colours, e.g. pink, black, turquoise, and white, have been assigned to hydrogen and linked to other production methods (Deloitte, 2023); these are not explicated here, as they are irrelevant to the study.

The value chain of green hydrogen

Besides the colours of hydrogen, some basic information about the hydrogen economy value chain is also considered relevant, as it helps show the study's boundaries.

Figure 2 depicts the simplified hydrogen value chain in four steps. Step 1 is the production of renewable electricity and the transmission of the electricity to the electrolyser plant. Step 2 is the green H_2 production via electrolysis. Step 3 comprises the H_2 transport and also H_2 storage. There are various options available for transporting and storing H_2, for example, in compressed or liquefied form in trucks or gaseous form in pipelines, as derivatives such as ammonia, for example. Step 4 shows some usages of the H_2 and indicates the usage of O_2 and usage for the heat.

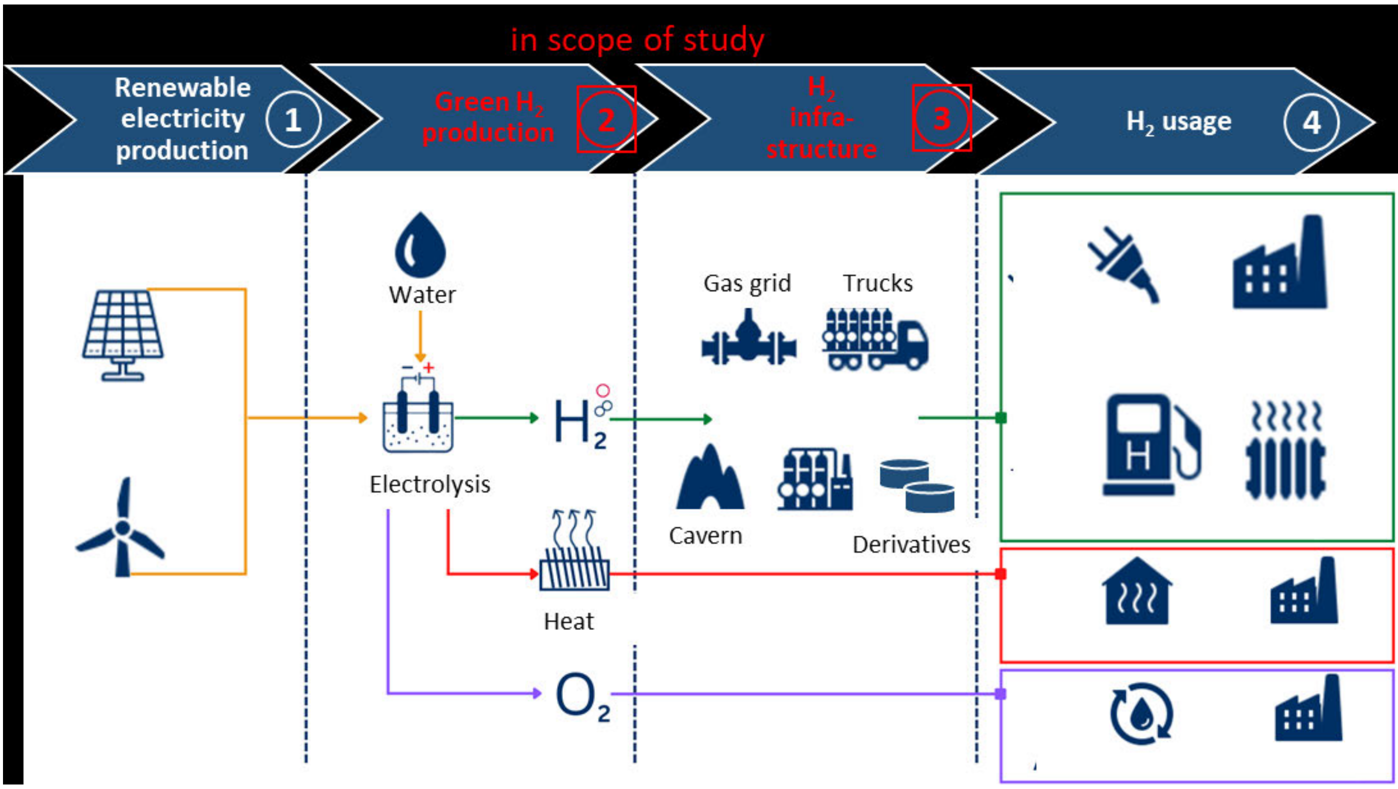

Figure 2 Simplified value chain of the hydrogen economy (adapted from [WTSH Landeskoordinierungsstelle](#) (2023))

In the study's main phase, the focus was put on the investigation of H_2 production projects and H_2 infrastructure projects, as explained above. So, value chain Step 2 and Step 3, labelled in red in Figure 2, are in the study scope; Step 1, renewable electricity production and Step 4, usage of H_2, are out of the study scope.

Having explained the relevance, the motivation, the aim and the background information for the study, the reader should be well prepared on what to expect and not to expect from the study. The next section presents the structure of the remaining study.

1.6. The structure of the thesis

The thesis is organised into two distinct parts, each serving a crucial purpose in advancing the research. Part 1 establishes the theoretical framework, laying the groundwork for the study. It comprises four comprehensive chapters, covering an introduction to the research field, a thorough literature review, the philosophical underpinnings guiding the study, and a detailed exposition of the research methodology. Transitioning to Part 2, the focus shifts to the practical application of the thesis, where empirical work takes centre stage. Mirroring the structure of Part 1, Part 2 also encompasses four chapters. The initial two chapters present the fieldwork, followed by a pivotal discussion chapter and culminating in the concluding chapter, which encapsulates the key findings and implications of the research. This structured approach ensures a seamless progression from theoretical foundation to practical implementation, resulting in a comprehensive and coherent thesis.

Chapter 2 systematically reviews the literature in the two fields of "business models/business model innovation" (BM / BMI) and "green hydrogen projects / green hydrogen economy". The review was conducted as a systematic review (Tranfield, Denyer, & Smart, 2003) supplemented by in-depth searches like citations or cross-references. Two questions guided the search. One was to find out about business elements, drivers and parameters relevant to future hydrogen projects, and the second was to discover the interrelationships between these elements.

These questions could not be answered directly, as the literature review revealed that no business modelling framework or concept or business model building blocks are available for green hydrogen projects. Thus, the research questions were answered by synthesising relevant information about BM / BMI gained from academic literature and extracting relevant information about green hydrogen projects / green hydrogen economy from grey literature, i.e. non-academic literature.

The ongoing discourse surrounding sustainable and circular business models, as exemplified by the works of Centobelli et al. (2020) and Galvão et al. (2020), alongside discussions on business model frameworks integrating external factors and macroeconomics, such as those by Jocevski, Arvidsson, and Ghezzi (2020), and Wirtz and Daiser (2017), holds significant relevance for this study. Moreover, in the context of the green hydrogen economy, the guidance provided by governmental publications outlining hydrogen strategies, funding programs, and regulatory policies emerges as pivotal for this investigation.

The answer to the two questions and a graphical idea of how the business models operate as activity systems (Casadesus-Masanell & Ricart, 2010; Zott & Amit, 2010), comprise the initial conceptual framework for the study.

Chapter 2 concludes by stating the need for further research. In a few words, that is to develop a business modelling framework for the hydrogen economy, including the industry-specific taxonomy.

Chapters 3 and 4 present and explain the research design. Chapter 3 consists of the chosen philosophical approach and the underlying paradigms; Chapter 4 reveals the research design in detail, comprising the research strategy and the applied methods and techniques. Striving for coherence in the research design is highly desirable; coherence in this context means the philosophy should fit with the nature and the topic of the research, with its purpose and with the researcher's philosophical stance (e.g. Bryman & Bell, 2015; Easterby-Smith, Thorpe, Jackson, & Jaspersen, 2018). The nature of the research is an exploratory study into a complex issue, a major problem of our time, related to the challenge of global warming. The purpose of the research is to investigate and better understand emerging business model designs that might be a means to facilitate the ramp-up of the hydrogen economy. The researcher's stance is that of an engineer, ontologically believing that real objects exist in the world, independent from human perceptions, and also that of a manager, having experienced epistemic relativism, which means that human knowledge is context and time-dependent and subjective.

Chapter 3 maps out the philosophical foundations on which the study settles. Having reviewed the available research paradigms from positivism to constructivism and considering that coherence in the research design is important, the choice was made to conduct the research under a critical realism paradigm and include system thinking concepts.

Critical realism is a moderate paradigm that supports pluralism, mixed and multi-method approaches (Gray, 2013); system thinking is studying phenomena holistically in their systemic behaviour and not isolated by their components (Bertalanffy, Boulding, Ashby, Mead, & Bateson, 1968). Philosophically, the study is based on the concepts of multiple layers of reality, hierarchically organised structures, non-linear causalities and generative powers (Bhaskar, 2013; Mingers, 2014).

Chapter 4 presents and explains the research design, which centres on conducting a qualitative case study focused on the German IPCEI projects. The aim is to delve deep into the intricacies of business modelling within the burgeoning H_2 economy. In selecting the methodology, inspiration was found in the works of Eisenhardt (1989) and Yin (2018), whose recommendations guided towards the case study approach. The fieldwork unfolded in two distinct yet interconnected phases: the screening phase and the main phase. While sequential, these phases overlapped to ensure a comprehensive exploration. During the screening phase (phase 1), the primary goal was to gain insights into the current status of the IPCEI projects. This involved a multifaceted approach, including thorough desk research, engaging in insightful phone discussions with project contacts, and distributing a survey among project actors. The findings from this initial phase played a pivotal role in refining the design of the subsequent main phase.

The main phase (phase 2) collected data from project actors and other stakeholders from various data sources. Mainly, 16 semi-structured interviews of 702 minutes and relevant conference contributions of 425 minutes have been collected.

The data was coded, thematically analysed, and then compared to theory. The theory applied for comparison was the initially developed conceptual framework at the end of the literature review and, in general, the concepts about business modelling found in the literature.

Although a prescriptive study design has generated some a priori codes, the majority of the codes were inductively generated from the data.

Chapter 4 also includes a reflection on the research design, the assessment of the research design's quality, and the ethical evaluation. The research is not expected to bear critical ethical issues.

Chapter 5 describes the fieldwork and the outcomes yielded during the screening phase. This initial stage served dual purposes: firstly, to garner insights into the current status of the IPCEI projects, and secondly, to refine, where necessary, the detailed design for the forthcoming main research phase. To achieve this, a comprehensive array of methods was employed, including desk research, phone interviews, and a meticulously crafted survey. The findings from the screening phase revealed a landscape marked by dynamic changes since the inception of the projects in May 2021 (BMWI, 2021a). Notably, many projects have withdrawn from the IPCEI program, while others are grappling with significant delays and widespread dissatisfaction among project stakeholders. As a result, the focus for the main research phase was put towards examining complex projects that persist within the IPCEI program. Specifically, the attention now centres on projects concerning H_2 generation and those addressing H_2 infrastructure, where significant potential and challenges lie.

Chapter 6 describes the fieldwork, the data processes, the first analysis and the results of the main phase (phase 2). The fieldwork collected qualitative data from 16 semi-structured interviews, 17 conference contributions and five documents; in total, 38 files were imported into NVIVO and qualitatively analysed. The coding process and the thematic analysis process are documented in Chapter 6. The chapter presents the findings for the three research questions in narrative, tabular and graphical form.

For research question 1, what elements are the (future) business models existing of? Four themes, ten business model dimensions, e.g. governance, finance and investment, actor roles and many choices available for the business model design have been found. For research question 2, how are those elements interacting? Three themes in 18 influencing factors, e.g., market design, CO_2 pricing, and quota obligations, have been found. For research question 3, what business model designs are considered today for upcoming large-scale green hydrogen projects? There were three themes, but there was no uniform opinion of the participants, and only one business model design that is feasible today was identified.

A thematic map was developed to show how the ten themes are linked, paving the way to the discussion chapter.

Chapter 7 discusses the findings in reflection on the literature and the underlying methodological concepts. The views about business models as activity systems (Zott & Amit, 2010) consisting of various building blocks (Wirtz, Pistoia, Ullrich, & Gottel, 2016) being composed by selecting from a range of choices (Baden-Fuller & Morgan, 2010; Casadesus-Masanell & Ricart, 2010) can be confirmed.

Then, an attempt was made to explain causality, i.e., to explain which factor(s) caused what effect. As linear explanations failed, an excursion into systems theory, complex systems and network theories (Amaral & Ottino, 2004) was undertaken to explore whether these holistic concepts could explain causality better than the reductionist approaches. The concepts look promising, but further research would be needed to assess them.

Chapter 7 also introduces an innovative conceptual framework, termed the "business meta-model of H_2 economy," drawing upon the hierarchical business model concept proposed by Osterwalder et al. (2005). Chapter 7 concludes by succinctly summarising the findings, addressing the research questions, and providing insight into the generalizability of the results.

Chapter 8 concludes the study. The chapter repeats the aim, objectives and research questions and summarises the findings and results. The results' quality and ability to answer the research questions are critically assessed in the next paragraphs. Then, the chapter outlines the contributions to theory and practice. The main contributions to the theory consist of drafting a business meta-model for the H_2 economy that is based on and expanding the hierarchical business model concept of Osterwalder et al. (2005). The main contributions to practice are experience sharing about project developing processes and related hurdles and drivers, the mapping of the business logic as perceived by project actors in real projects, and, even more so, the information about available choices to design business models. Chapter 8 closes with reflections on the limitations and generalisations of the study and gives ideas for further areas of research. The thesis concludes with the author's personal reflections about the research journey and a concluding wrap up.

Part 2 of the study includes fieldwork phases 1 and 2, discussion, conclusions, and contribution chapters (Chapters 5-8). The following graphic (Figure 3) aids in understanding the structure of Part 2. Part 2 begins with the screening phase investigating "RQ 0" and "Objective 0" (Figure 3). Chapter 5 presents the screening results that also inform the main phase. Three research questions (RQ1, RQ 2, RQ 3) and three objectives are addressed in the main phase, with results presented in Chapter 6. Further analysis provides answers to all research questions (Table 10) and the development of conceptual frameworks (Figure 35 to Figure 37).

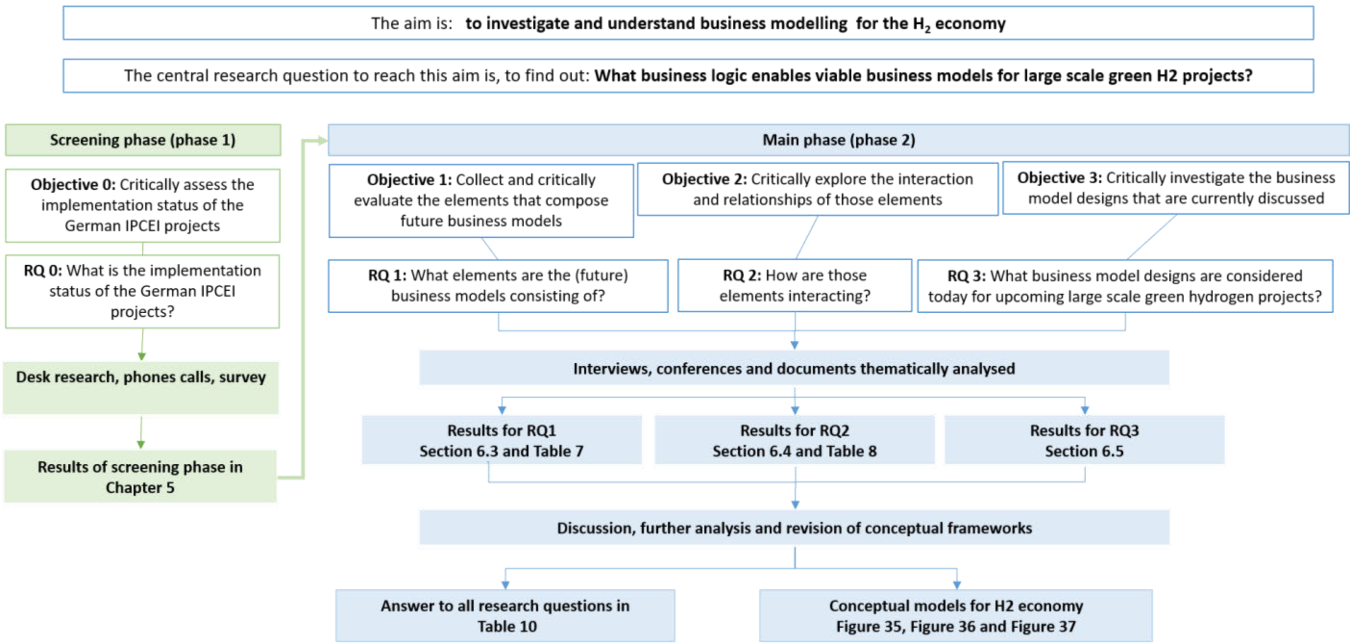

Figure 3 Overview over Part 2 of the study (author's own)

2. Literature review

2.1. Introduction to the literature review

For this study, the decision has been made to apply as far as possible a systematic literature review, following the “evidence-informed approach” as proposed by Tranfield et al. (2003, p. 207). The advantages of systematic reviews are that they follow a replicable and transparent process that is made explicit (Tranfield et al., 2003). Systematic reviews have their origin in the medical field; by applying them in the field of management, the clearly planned and conducted process helps to enhance rigour and academic robustness. However, the complex and fast-developing situation in the field of hydrogen partly prevented a fully systematic approach (see Section 2.7 for limitations and critics).

Engaging in a systematic literature review entails structuring it akin to an independent research endeavour nested within the broader research project. This approach signifies that the literature review possesses distinct research questions, an underlying premise, and, in this instance, an autonomous methodology. It is meticulously planned, executed, and documented in a transparent and accountable manner.

This literature review is structured in eight sections. Section 2.2 introduces the research questions, the underlying assumption and the paradigm for this literature review. Section 2.3 presents the search strategy and the methods that have been used. Sections 2.4 present the results. Section 2.5 and Section 2.6 further process the results of the previous sections and synthesise them to present the answers to the literature review questions and to develop the initial conceptual framework that has guided the main study. Section 2.7 reflects on the approach selected for the literature review by noting limitations and critics. Section 2.8 concludes the chapter by summarising the need for additional research revealed through the literature review.

2.2. Research questions, assumptions and paradigm

At its core, the research is about business modelling for large projects in the hydrogen economy. The research is nested in the context of the worldwide energy transition.

The literature review aims to critically evaluate existing theoretical frameworks, propositions and theories with regard to their applicability and suitability to use them for analysing the business models deployed up to date to those new upcoming projects. By reviewing the relevant academic and non-academic information on the fields of research, this literature review creates the initial conceptual framework for the fieldwork.

Drawing on the initial assumption that well-designed business models could be conducive to the realisation of hydrogen projects, two research questions were developed for the literature review:

(1) What elements, drivers and parameters are potentially going to play a role in future business models for building large-scale green hydrogen projects?

(2) What might be their relationships and their interdependencies and modes of action?

Design Science Research Paradigm and why it is considered an appropriate approach for this literature review research

J. E. v. Aken (2004), Hevner (2007), Denyer, Tranfield, and Aken (2008) and others argue that design science can help management research gain more practical relevance without losing academic rigour. Design science research looks at the prescriptive logic and the generative mechanisms inherent in the subject under study through a structured process providing rigour and academic validity. But it is also pragmatic by allowing "fit to purpose" approaches (J. E. Aken, 2005; J. E. v. Aken, 2004; Tranfield et al., 2003) and it hence offers a structured process, rigour and academic validity.

An exemplary application of design science can be found within the domain of engineering. New machines are designed by grounding them on technological rules (Aken, 2004) and by respecting design propositions specific to the related domain of engineering (Denyer et al., 2008). These foundational guidelines, alongside consideration of detailed requirements, form the basis for developing an initial design for the new machine. Following, this initial design phase, a prototype is constructed in alignment with the newly developed design specifications. Subsequently, rigorous testing of the prototype invariably uncovers areas ripe for improvement, prompting a thorough revision of the design. This iterative process encapsulates what is known as "Design Science Research Cycles" (Hevner, 2007), wherein continual refinement leads to progressively enhanced outcomes.

Similarly, the business model design process to be investigated in this research follows the same logic. This literature review provides a preliminary draft of the “technological rules” and design proposition synthesised from literature potentially applicable to the business model design for green H_2 production. The results of the systematic literature review are synthesised in the conceptual framework (Section 2.6), and the research questions are answered in Section 2.5.

2.3. Search strategy and methods

For reasons of transparency and replicability, the method of a systematic literature review (SLR) has been applied, following the recommendations of Tranfield et al.

(2003). Tranfield et al. (2003) adapted the method, which is traditionally used in the medical field, to that of management. A thorough audit trail on search terms, inclusion/exclusion criteria, searched sources, and the process of quantitative and qualitative data analysis is kept (see Appendix 1). This is advantageous, as this literature review was updated during the work on the study. All in all, the literature review process took place from December 2020 until January 2024.

Prior to the actual literature search, scoping studies (Pawson, 2006) were conducted to gain an overview of the available information and to find the best search terms for the systematic literature review. The scoping study revealed that there is almost no literature that considers business models and green hydrogen projects or economies together. As a result, the literature search was divided into two searches. One search is on business models and business model innovation, and one search is on the hydrogen economy, respectively, green hydrogen projects.

Literature review on BM / BMI – umbrella review

There is a large body of literature available in the field of business model and business model innovation. An umbrella review, i.e. a search for already existing systematic literature reviews in the field, was carried out first, i.e. at the beginning of the study. The following search terms were defined:

- “business model”; “business model innovation”; “business model research”; “business model change” AND “systematic review” OR “systematic literature review”

The search encompassed databases renowned for their expansive coverage and robust search capabilities: the Web of Science (WoS), specifically its Core Collection, and EBSCO, which includes databases like Business Source Complete, eBook

Collection (EBSCOhost), and Environment Complete. These platforms were chosen due to their wealth of articles and efficient search and clustering features. Given the relevance of the subject matter, the search was confined to the most recent five-year period (2017 to 2021), with language filters set to include only English and German publications; no restrictions were placed on peer-reviewed status. The query yielded 85 results from WoS and 690 from EBSCO. The screening process involved abstract evaluation and application of predefined inclusion and exclusion criteria (as outlined in Table 1), along with an assessment of each article's potential to address the research questions, a total of 19 systematic literature reviews (SLRs) were deemed pertinent and integrated into the study database. Figure 4 provides a visual representation of the literature review process. The literature review activities conducted included a deep dive into the content of the meta sources, specifically focusing on the findings and methodologies of the 19 systematic literature reviews on business modelling to gain a comprehensive understanding of the research field. The quantity and calibre of the selected SLR articles were found to be comprehensive, effectively covering the focus of the search with depth and relevance.

Table 1 Inclusion and Exclusion criteria for literature review on BM and BMI (author's own)

Inclusion criteria	Exclusion criteria
• contains information about how to structure business models • offers concepts on relationships between elements of business models • takes a systemic, holistic approach • applies concepts to real cases	• focus on non-European region • focus on end-customer business (consumers) instead of Business-to-business • focus too narrow (e.g. one product, one sales channel)

<u>Literature review on BM / BMI – In-depth search and snowballing cross-reference technique</u>

The initial scoping review revealed three articles (Casadesus-Masanell & Ricart, 2010; Demil & Lecocq, 2010; Zott & Amit, 2010) being of high relevance for this research, because of their view on business model and business model design or because of the theoretical concept they present. These articles have become core articles and were the starting point for the further in-depth search.

A comprehensive search strategy, inspired by the snowballing method proposed by Wohlin (2014), was employed to explore further developments and practical applications related to the concepts discussed in these three papers.

The snowball review was conducted by starting with the above mentioned three core articles and from there systematically expanding the search by examining the references of these key studies to uncover additional relevant sources. From those additional resources again the references were examined to further expand the search along the relevant streams. Following this methodology outlined by Wohlin (2014) as “snowballing technique”, forward and backwards citation searches allowed for a comprehensive exploration of the literature landscape and ensured that the relevant studies were included in the review.

Utilising both Google Scholar and Web of Science (WoS), this forward citation and cross-reference search technique aimed to uncover recent publications that build upon or utilise the discussed concepts of the core articles. Through this method, the initial in-depth investigation successfully identified 22 additional articles, enriching the database significantly (refer to Figure 4).

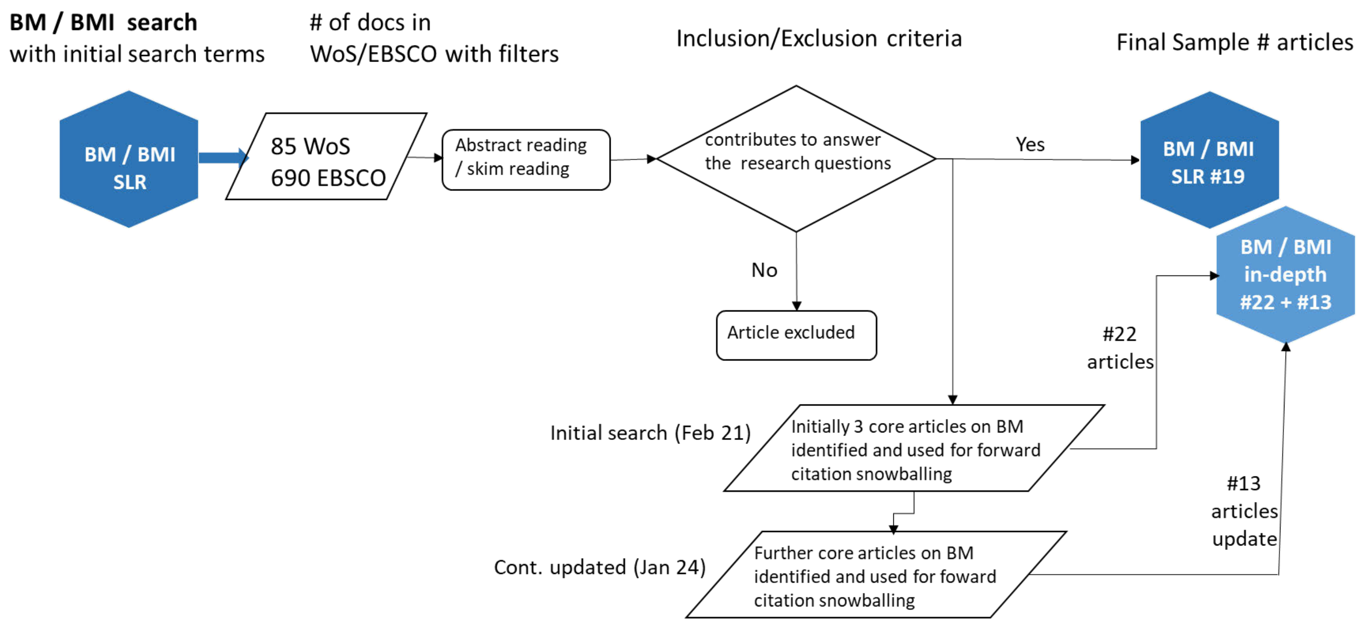

Figure 4 Business model / Business model innovation literature search process (author's own)

The literature base on business modelling was continuously updated during the course of the study, as it was learned that external conditions and macroeconomics currently have a large influence on business model design and that theories about complex systems and networks could also be useful for the study. Consequently, the literature database was continuously expanded, and a further 13 articles were added (see Figure 4).

Literature review on green hydrogen

The database review on green hydrogen was performed at the beginning of the research (February 2021) in WoS and EBSCO, analogue to the search about BM and BMI. The following search terms have been used:

- “hydrogen economy"; “hydrogen”; “green hydrogen”; ”hydrogen project“; “eco-innovation“ AND “systematic review” OR “systematic literature review”

As the search for academic references has led to no hits (see Figure 5), non-academic sources built the basis for the literature review for the green hydrogen field.

Governmental publications, such as hydrogen strategies, studies and reports published by renowned institutions, such as the International Energy Agency (IEA), the International Renewable Energy Agency (IRENA) and the World Energy Council (WEC), have been searched. In total, this first set comprised 16 files (Figure 5).

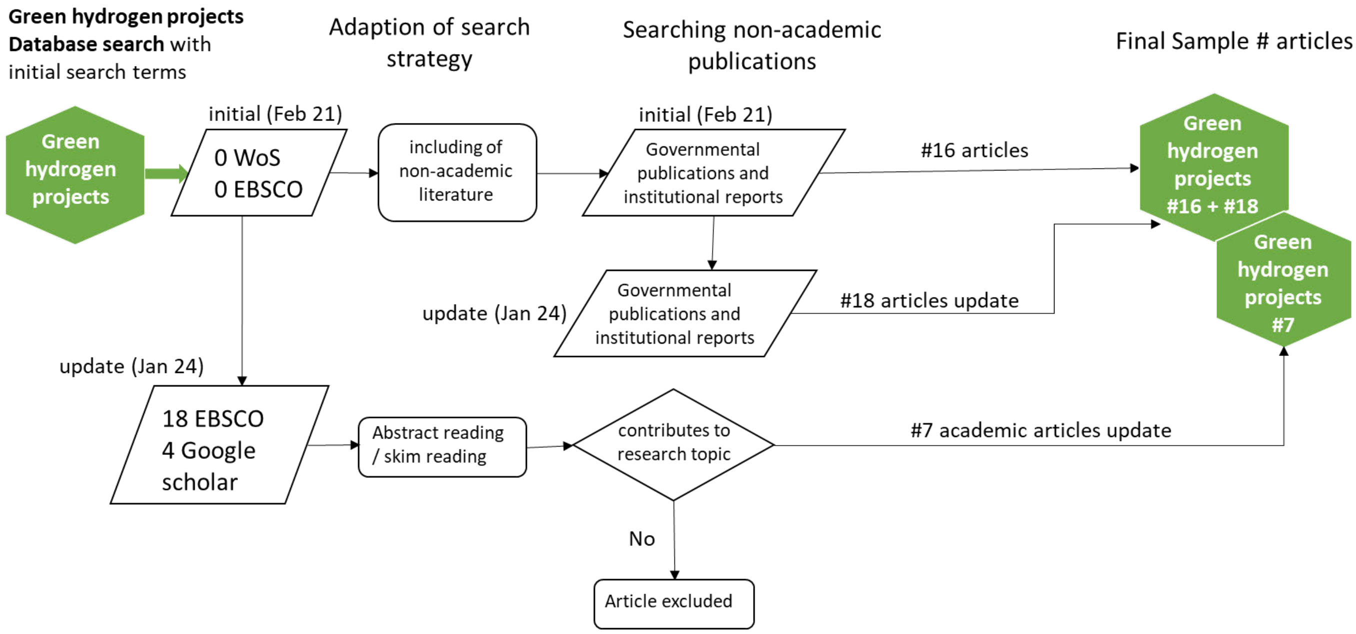

Figure 5 Hydrogen / Green hydrogen projects literature search process (author's own)

During the course of the research and at the end of the research, the literature review was updated. Again, the databases EBSCO (filter set on "in-text") and also Google Scholar (filter set on "in title") have been searched with the following search terms:

- "business model" AND hydrogen

In January 2024, the database query yielded valuable results: 18 hits from EBSCO and 4 hits from Google Scholar. After screening for relevance, a selection of seven high-quality academic articles have been selected and integrated into the literature review database (see Figure 5).

Updating the non-academic resources at the end of the study was very important for its timeliness and for understanding the results in Part 2. In the past three years, many new studies, reports and statements on the hydrogen economy have been published. These are, for example, the updates of the hydrogen strategies, numbers of published policies and press releases from the EU and the German government, updates of institutional reports and numbers of studies and reports from various research institutes and associations. In total, 18 files have been added to the literature base (Figure 5). In addition to the articles and reports included in the database, many websites also contribute to the non-academic information.

Method of analysing the literature review data sets

The literature sets were analysed quantitatively by assessing the balance, the quality and the quantity of sources included for the two fields of the search. The results of this descriptive analysis are presented in Section 2.4.1; more details are available in Appendix 1.

The qualitative analysis of the datasets was conducted using NVIVO, facilitating an examination of their content through coding. NVIVO was selected early on in the process, primarily to maintain organisational efficiency and establish a clear audit trail, a decision that ensured a systematic approach from the outset. The literature review served dual purposes: firstly, to explore the ongoing discourse, identify gaps, and discern emerging trends within the two targeted fields, and secondly, to lay the groundwork for developing an initial conceptual framework essential for guiding the main study.

The current debates have been summarised from the NVIVO content codes (Appendix 1) of the various data sets and are presented in Sections 2.4.2 and 2.4.3 as narratives.

The conceptual framework for the research was developed by answering the literature research questions. The CIMO-logic (Context-Intervention-Mechanism-Outcome) (Denyer et al., 2008) helped to organise the answers in table format. The CIMO logic can be helpful in understanding system behaviour by investigating interventions that generate outcomes and understanding the related generative mechanisms; it thus supports the systemic approach this study aims to take. The answers to the research questions and more discussion of the CIMO logic are provided in Section 2.5. The initial graphical conceptual framework (Section 2.6) aimed to visualise how a business model for hydrogen might function as an activity system.

2.4. Literature review: Results and Discussion

2.4.1. Results: Descriptive analysis

Figure 6 provides an overview of the number and type of articles included in this literature review.

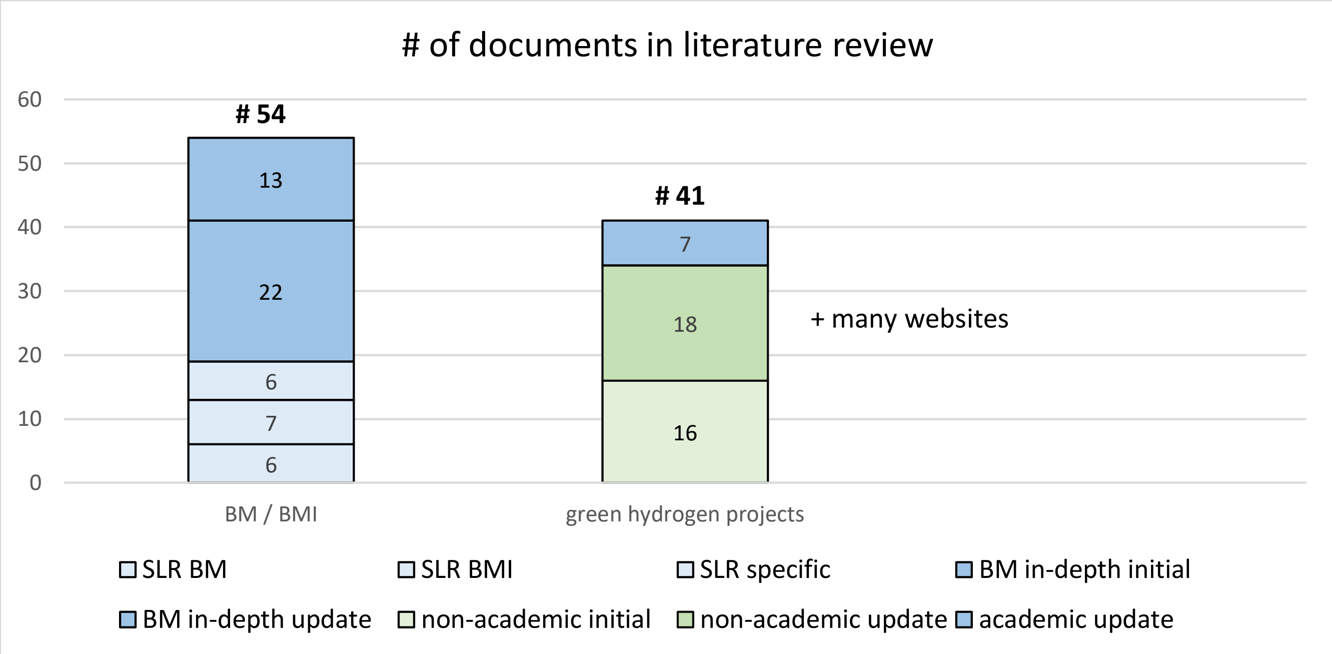

Figure 6 Number of documents included in the literature review (author's own)

In the realm of business model research and innovation, the comprehensive analysis encompasses a total of 54 rigorously peer-reviewed academic publications. Among these, 19 are systematic literature reviews, offering a panoramic view of the field, while the remaining 35 in-depth academic articles elaborate on different aspects of business modelling, that have been assessed as being relevant for the study. It is noteworthy that all these articles have been published within the last six years, ensuring the relevance and timeliness of the analysis.

The umbrella review, i.e. the 19 systematic literature reviews, represents over 3000 articles that have been included by their authors. They are well balanced between SLRs on general business model research (Figure 6 "SLR BM"), compiling the general state-of-the-art in business model research, SLRs on business model innovation (Figure 6 “SLR BMI”), investigating the state-of-the-art and key components in business model innovation and specific SLRs (Figure 6 “SLR specific”) that are considered relevant for this study, because they include ecological aspects, e.g. reviewing circular economy business models or interconnected business models or sustainable elements in business model design. More bibliographic information about these SLRs is given in Appendix 1.

The selection of articles within the BM/BMI field has been carefully curated to align with the specific methodologies pertinent to this study. These methodologies, such as systems theory or design science approaches, offer valuable insights essential to the research objectives. Furthermore, the chosen articles closely resonate with the study's focus, particularly in exploring business models within volatile, uncertain, complex, and ambiguous (VUCA) environments or those pertaining to energy storage.

For the field of hydrogen and green hydrogen projects, in total, 41 files are included, of seven academic and 34 non-academic sources; in addition, many websites have been visited for gathering information.

The academic articles have been published very recently, in 2022 or 2023. They investigate business model aspects related to hydrogen in some way, e.g. for sector coupling or for energy systems. The non-academic sources are government publications by the EU or the German government on hydrogen strategies and regulations or reports from international agencies on the status of the hydrogen market ramp-up.

2.4.2. Results: Narrative – State-of-the-Art in BM / BMI Research

The following narrative about the current state of the art in the research field of BM / BMI is informed by the qualitative analysis of the set of systematic literature reviews conducted in NVIVO; the coding for this analysis is documented in Appendix 1.

Research on “business models” and “business model innovation” seems to be very popular; both concepts are extensively researched, and the steep rise in the number of publications in particular in the last five years is noted by many authors (e.g. Belussi, Orsi, & Savarese, 2019; Isensee, Teuteberg, Griese, & Topi, 2020; Täuscher & Abdelkafi, 2017)

But despite this enormous body of literature, many authors state that there is still a lack of common understanding of the concepts (e.g. Belussi et al., 2019; Cuc, 2019). Multiple definitions, categorisation and perspectives exist. Business models can be defined as "the core business logic" of a company (Osterwalder et al., 2005; W. Zhang & Banerji, 2017) or as an “activity system” (Cuc, 2019). They can be viewed from different perspectives, such as strategic and innovation management and marketing and organisational design perspectives (Belussi et al., 2019). Various categorisations exist for the elements composing a business model; those are, for example, customers, suppliers or, one level of abstraction above, value creation, value transfer and value capture (Centobelli, Cerchione, Chiaroni, Del Vecchio, & Urbinati, 2020). These are only some of the taxonomies drawn from the qualitative content analysis to exemplify the heterogeneity and variety of descriptions for the concepts.

<u>Trends and gaps</u>

The reviewed SLR articles also describe trends and gaps in the field of BM / BMI research. An important trend to mention is that "business model innovation", originally a subfield of BM research, has become a major research direction on its own. The development of the internet during the last two decades has created many new business models around digitalisation. The investigated SLRs unanimously name business model innovation and digitalisation, such as Industry 4.0, e-commerce and big data, as the current focus of BM research. Some SLRs also mention servitisation, i.e. the attempt to expand goods-based offerings to service offerings, as a trend in BM research (W. Zhang & Banerji, 2017).

One of the focal points in this research revolves around the dynamic interplay of ecological, societal, and environmental considerations within business models, as highlighted by Centobelli et al. (2020). Referred to as sustainable business model (SBM) development or circular business model (CBM) development (Centobelli et al., 2020; Galvão et al., 2020), these frameworks extend beyond traditional economic metrics to encompass broader value creation. Specifically, they emphasise the integration of environmental and societal benefits alongside economic gains.

In addition to the demand for clearer definitions and simplification of taxonomies and typologies, some authors also see the need for a more confirmative than exploratory approach to BM research (Belussi et al., 2019, p. 15) and better grounding in theories, such as system theories for instance (Cuc, 2019, p. 14).

This brief outline of the scientific status shows, on the one hand, that the topic of business model research is highly topical. On the other hand, there is a large number of concepts and perspectives available therefore the approach used for the investigation of green hydrogen production projects should be carefully tailored and focused in order to achieve the aim of the research. The remaining explications in this chapter describe how the many available approaches to investigating business models were narrowed down and how a few concepts that seem most appropriate for the research were selected. Chapter 2.6 then describes the development of a conceptual framework for this research, which builds the initial underlying theory for the fieldwork of the thesis. The conceptual framework is developed by synthesising and tailoring the selected key concepts and enriching them with elements and ideas of other concepts found in the academic body of BM research.

Dynamic business model view - perspective adopted for this research

In the realm of business model (BM) research, there are two primary streams of thought that delineate how BMs are understood. One perspective characterises BMs as static configurations comprised of diverse building blocks, highlighting the involvement and presence of various stakeholders. On the other hand, another viewpoint sees BMs as dynamic systems of interconnected activities and participants, constantly in flux. Gassmann, Frankenberger, and Csik (2013) present a visual representation of the former concept with their "magic triangle," while Osterwalder, Pigneur, Oliveira, and Ferreira (2011) offer the well-known "business model canvas" framework as an exemplar. Conversely, Zott and Amit (2010), Casadesus-Masanell and Ricart (2010), and Demil and Lecocq (2010) are prominent scientists advocating for the latter perspective, emphasising the fluid nature of BMs and their constituents.

Meanwhile, in their over 3000 times cited article “Business Model Design: An Activity System Perspective”, Zott and Amit (2010) developed the idea that a business model can be viewed as an activity system of interdependent or independent relations involving different kinds of resources (e.g. human resources, capital, physical) of different players (focal firm, suppliers, end customers). This approach is attentive towards choices and changes made by the parties or coming from the external environment. Demil and Lecocq (2010) develop these ideas into a framework that comprises resources, competencies, organisation and value proposition (RCOV framework), and coin the term "permanent disequilibrium" to express, that business models underlie a constant process of change and interplaying forces of the diverse parties, which are never fully balanced.

The paper “From Strategy to Business Models and Onto Tactics" by Casadesus-Masanell and Ricart (2010) has also been chosen as a key article that helps to develop a conceptual framework because of its practicable approach to analyse business models by identifying main causal chains within the business model activities. The authors elaborate on relationships and causalities, or using their words "choices and the consequences", which induce different business models with "different specific logics" (p. 198), creating value for the stakeholders. They also propose distinct levels of aggregation for the analyses of business models to prevent becoming lost in detail. In their paper, they use their framework for the analyses of the business models of Ryan Air and two other companies. Casadesus-Masanell and Ricart (2010) propose to use the metaphor of a machine, for instance, a car, to understand how a business model is composed and how the logic of operation is created. The car, being the BM, consists of many individual components that interact logically in a purposeful way; furthermore, the car can be driven to different destinations by a knowledgeable car driver.

This analogy can also be applied to the topic of this research:

Consider green H_2 production projects as intricate systems, echoing the insights of Zott and Amit (2010), who liken them to activity systems comprised of numerous interdependent components collaborating purposefully generating green H_2. Every decision, from selecting components to designing interconnections, carries ramifications, fostering a web of interconnected feedback and consequences. This conceptual framework serves as the cornerstone for the subsequent development of theoretical underpinnings and the fieldwork analysis (Chapter 2.6).

Further articles, building either on those core papers' ideas or adding other elements coming from the ideas of SBMs and CBMs, have been identified in the in-depth search. Findings from those articles, contributing answers to the research questions are also integrated in Chapter 2.5 and have contributed to the development of the conceptual framework, presented in Chapter 2.6.

View on macroeconomics, hierarchies and modelling – relevant perspectives for this research

The ramp-up of the H_2 economy is very closely linked to the EU targets and the resulting national laws and requirements in relation to climate protection and decarbonisation. A range of regulations is enacted or under discussion, Section 2.4.3 expands on the details. For the business model design process, this means that frameworks that explicitly consider the external, macroeconomic influences on business model design are considered to be relevant for this study. There seem to be fewer authors applying a macro-economic view on the business model than there are applying a microeconomic view. A few recent publications have taken up the topic. For example, Jocevski, Arvidsson, and Ghezzi (2020) have done a meta-study to explore the literature about "interconnected business models". They acknowledge the external links a firm entertains to its partners, suppliers and customers and the mutual impact those relations have on each of the partners' business model. They come to the conclusion that "the BM concept may be seen as a multi-level device that would allow different scales to be adopted for analysis, i.e. would allow managers to observe a value architecture from three different viewpoints." (Jocevski et al., 2020, p. 1062). They then go on to explain the three levels which very much corresponds to what

Osterwalder et al. (2005) have presented with their “Business Model Concept Hierarchy” (p.5). Foss and Saebi (2017) review the process of business model innovation in their over 2000-times cited article “Fifteen years of research on business model innovation: How far have we come, and where should we go?”. They conceptually introduce parameter, that they call “moderators” on three levels, macro-level, firm-level and micro-level that moderate the business model innovation process. For the macro level moderators, they give some examples, such as legislation, labour law, competition law etc. that might exercise influence on the type of business model that can emerge or not. They conclude that business model research lacks the anchoring in macro-economic environment. B. Wirtz and P. Daiser (2017) propose a conceptual framework including macro-level and micro-level environmental dimensions of a business model innovation. For each level, four categories are given, for the macro level these are “Globalization”, “Technology”, “Regulatory / Economic Issues” and “Industry /Market Shifts”. According to B. Wirtz and P. Daiser (2017) those macro and micro-level dimensions interact with the business model innovation factors “Who”, “What” and “How” in a dynamic way. Although this framework presented by Wirtz and Daiser (2017) remains at a superficial level, it is one of the few concepts that takes macroeconomic issues into account at all, therefore it is of relevance for this study.

During the screening phase, as discussed in Chapter 5, it became evident that the initial approach—to examine existing business models within the H_2 economy—was not viable due to the scarcity of practical models. This realisation underscored the exploratory nature of the study, surpassing the initial expectations. Consequently, the investigation will pivot towards a more conceptual exploration rather than focusing on specific projects or companies. In their seminal work, "Clarifying business models:

Origins, present, and future of the concept" (Osterwalder et al., 2005), the authors provide helpful definitions and a three-level hierarchical framework for understanding business models. This foundational piece has garnered significant attention, cited over 6000 times, and is lauded by the authors for its aim to enhance comprehension and provide a comprehensive terminology and ontology for describing business models. Drawing from Osterwalder et al.'s insights, outlined in Chapter 7, their work serves as a guiding light for the deeper analysis. By offering clarity and structure to the concept of business models, it provides a robust framework to navigate the study effectively. Firstly, it provides a definition for the concept of business models, the first sentence in particular is adopted also for this study:

> A business model is a conceptual tool containing a set of objects, concepts and their relationships with the objective to express the business logic of a specific firm. Therefore, we must consider which concepts and relationships allow a simplified description and representation of what value is provided to customers, how this is done and with which financial consequences. (Osterwalder et al., 2005, p. 3)

Secondly, it provides a useful hierarchical topology of business model concepts at meta – model level, sub-meta model level and instance levels that model a real-world company. Figure 7 reproduces the graphic from Osterwalder et al. (2005) ‘s paper, as this model also has informed the newly developed conceptual framework explained in Chapter 7. It should be expressively noted that the choice of companies “Dell”, ”Amazon” and “eBay” in Figure 7 is in the original reference and not the choice of the researcher.

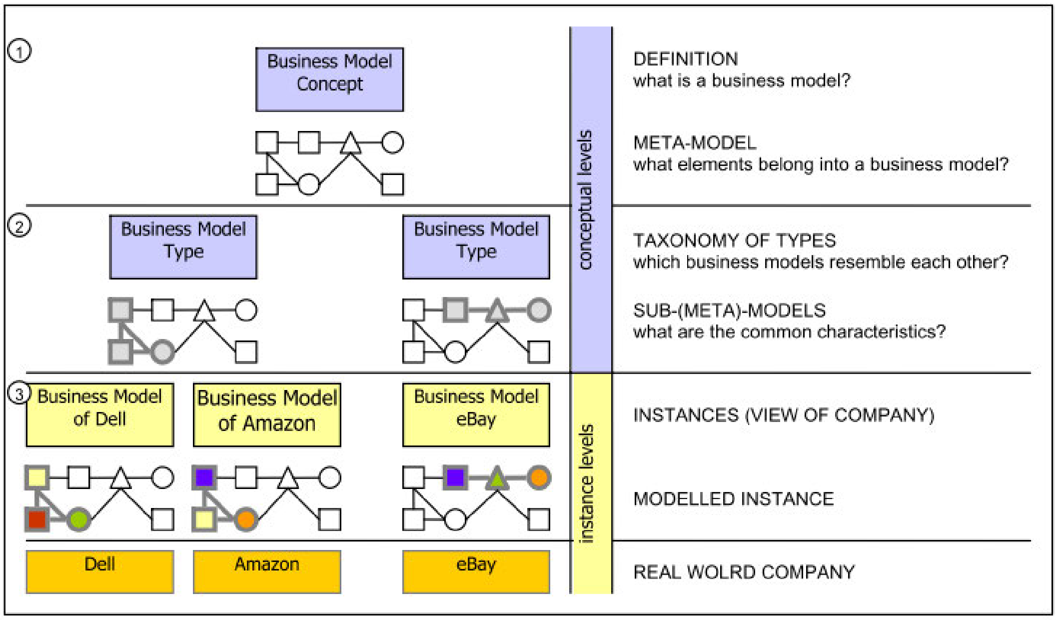

Figure 7 Business Model Concept Hierarchy (Osterwalder et al., 2005, p. 5)

Thirdly, the Osterwalder et al. (2005) paper proposes nine business model building blocks with the following definition, which is also adapted for this study:

> A business model is a conceptual tool that contains a set of elements and their relationships and allows expressing the business logic of a specific firm. It is a description of the value a company offers to one or several segments of customers and of the architecture of the firm and its network of partners for creating, marketing, and delivering this value and relationship capital, to generate profitable and sustainable revenue streams. (Osterwalder et al., 2005, p. 10)

The nine building blocks have also informed the initial conceptual framework, in particular Chapter 2.6, Table 2.

Lastly, the views about "Business models as models" (Baden-Fuller & Morgan, 2010) are relevant for this study. One point that Baden-Fuller and Morgan (2010) emphasise is, that models are not the real world, they are models of parts or parts of the system, that might help to understand how and why things operate as they do. Interpreting this argument, the investigation of business models in the H_2 economy automatically come with limitations, not everything can be explained by the model, but major lines of actions. Baden-Fuller and Morgan (2010) bring several metaphors for business models in their article: one more often used, also by other authors (e.g. Casadesus-Masanell & Ricart, 2010; Denyer et al., 2008) is the metaphor of a business model as a machine, consisting of parts that work together in a predefined way to produce something. Another frequently used metaphor is that of an organism that works in itself with all the biological cells acting together, but also is in constant exchange with its environment. Baden-Fuller and Morgan (2010) add the metaphor of business models as recipes, using a set of ingredients that can be cooked in different ways, some recipes result in a tasty meals and others not.

All those metaphors also resonate with the perspectives taken in this research with the line of enquiry taken, and with the way the findings and analyses are presented.

2.4.3. Results: Narrative – Debate on green hydrogen economy

This section presents the ongoing discourse surrounding green hydrogen, drawing from a variety of academic and non-academic sources. While predominantly sourced from non-academic outlets, a selected few academic resources also contribute to the discussion. Despite the diverse array of sources, the information directly pertinent to the focus of this research - namely, business model designs for green hydrogen projects - is somewhat limited. In light of this, the following elucidations distil key insights from the current discourse on green hydrogen, specifically those that bear relevance to the research objectives. This synthesis serves the dual purpose of furnishing background context and furnishing the requisite understanding to interpret the findings presented in Part 2.

Non-academic sources

Overall, it can be said that meanwhile, i.e. over the last three years of this study, a wealth of information about hydrogen playing a key role in the future energy system has become available. It is easy to find information about anticipated market sizes and investment needed to build up H_2 production structures and infrastructure (e.g. Deloitte, 2023; Hydrogen Council, 2023; IEA, 2023a; H. C. McKinsey, 2022) it is also easy to find information about the H_2 projects that are currently being planned (e.g. IEA, 2023b, 2023c; Worldhydrogenweek, 2023). The information that is publicly available today is also much more specific than that information that was available three years ago. This is well exemplified by the development of the German hydrogen strategy. First issued in 2020, the strategy paper elaborated on the recognising the potential of hydrogen as a future energy carrier, goals, ambitions and action plans were mostly formulated qualitatively (Die Bundesregierung, 2020). Whereas the update of strategy document, published in July 2023 (BMWK, 2023c) is far more specific, such as the naming of legal paragraphs in which the new framework conditions are to be anchored and the formulation of quantitative expansion targets.

The prevailing consensus across various studies remains unwavering: this was evident in the preliminary literature review conducted at the onset of 2021, and it persists three years later, as confirmed by the latest literature review at the beginning of 2024. By the end of 2023, the literature indicated promising prospects for green hydrogen projects, mirroring findings from the end of 2021. However, it also pinpointed areas for improvement and action items, particularly for policymakers, to facilitate market expansion. Highlighting pivotal topics encapsulating the ongoing discourse surrounding the hydrogen economy, several key themes, emphasised in bold, have been identified as pertinent to this study and are outlined below. (note of the author: the order of the themes does not represent the relevance):

- **a large market size for green hydrogen is predicted**

  For Germany, until 2030, 10GW of electrolyser capacity should be installed to cover roughly 50% of the hydrogen needed, estimated at 95 to 130TWh with domestic production. The remaining portion is to be imported, e.g. via H_2 derivate import by ship or H_2 directly by pipeline (BMWK, 2023c; IEA, 2023a). The market volume in 2050 is expected to be a multiple of that in 2030. Invest volumes in Germany are simulated at 5,6 billion EUR until 2035 (H. C. McKinsey, 2022).

- **Ensure availability of sufficient amounts of hydrogen, strengthen resilience**

  Russia's military attack on Ukraine in February 2022 marks fundamental paradigm shifts in German and European security, energy and industrial policy. Striving

  for energy independence from (Russian) fossil energy carriers and striving for diversifying the energy source, accelerates the need and motivation to ramp up the H_2 economy. Consequently, Europe and Germany have raised H_2 economy market demand and production targets; additional funding instruments to support this are under discussion.

- **Establishing favourable conditions for framing H_2 market demand and H_2 market supply and H_2 infrastructure and logistics**

  This is a very important key theme; see the next Section 2.4.4 for the current status.

In summary, all these studies agree on the basic narrative that hydrogen is going to play a significant role in the future energy system. They also forecast large future markets.

The role of policies in facilitating the ramp-up of a hydrogen economy is important. Studies consistently highlight the importance of well-designed policies in shaping the necessary conditions for its success. By strategically framing the regulatory landscape, governments can catalyse demand for hydrogen, such as by mandating green H_2 feedstock quotas for industrial processes to drive decarbonisation efforts. Furthermore, governments can support the transition financially, bridging the initial cost gaps between green and grey hydrogen through state aid initiatives. Additionally, by implementing supportive regulatory frameworks, they can streamline permission processes and regulate carbon prices, thus fostering an environment conducive to developing economically viable business models for green hydrogen production plants. Through these concerted efforts, policymakers can pave the way for a sustainable and thriving hydrogen economy.

The December 2023 editions of the Global Hydrogen Review Report (IEA, 2023a) and the Hydrogen Insight reports (Hydrogen Council, 2023) report that the market ramp-up of the hydrogen industry is lagging behind expectations. Investments in projects (Hydrogen Council, 2023; IEA, 2023a) are hampered; worldwide, only 7% (USD 39 billion) of the announced direct investment volume (USD 570 billion) until 2030 has passed FID (final investment decision), in Europe, only 4% (Hydrogen Council, 2023; IEA, 2023a). Contrary to the predicted cost decreases of 50% or more for green hydrogen until 2050 (Deloitte, 2023; IEA, 2023a), caused by scale effects and technological advancements (e.g. Goduni, 2022; H. C. McKinsey, 2022), de facto costs and cost expectations for H_2 projects have risen substantially since 2021. Some studies quantify the cost increases to 30-65% (IEA, 2023a) that have taken place in the last years, which poses a major obstacle to the realisation of projects.

None of the studies deal with business models or business model design; they do not even mention the term “business model.” This is surprising considering that the businesses of many companies, industries, and even countries are going to be impacted and considering the fact that some studies flag an alarmingly low rate for project FIDs.

Academic sources

The few academic sources that have been selected because they study business models for hydrogen applications are interesting in the following ways.

Several works acknowledge that profitability that only considers economic value is insufficient for achieving viable business models within the hydrogen economy. They propose to include social and environmental cash flow also into the considerations (Blanco et al., 2022; Matinmikko, Kinnunen, Sinkkonen, & Kärri, 2022; Trapp, Kanbach, & Kraus, 2022) They, therefore, drag the ideas on sustainable business model design, presented as a trend in business model research in Section 2.4.2, to the hydrogen industry. Blanco et al. (2022) also develop a model taxonomy to classify energy systems for the hydrogen value chain. However, this taxonomy does not refer to business model elements. Giehl, Hohgräve, Lohmann, and Müller-Kirchenbauer (2023) present a business model evaluation tool, called OBMET, that calculates the net present value (NPV) for Power-to-X and X-to-Power projects, provided the tool is fed with the relevant input information.

In concluding the literature review concerning the burgeoning field of the green hydrogen economy, it becomes evident that a wealth of grey literature exists alongside a burgeoning body of academic works exploring various facets of hydrogen as an energy carrier. Notably, some publications have begun to acknowledge the critical role of business model design in this domain. However, to the best of the author's knowledge, none have specifically taken the perspectives of project actors or investigated the essential prerequisites necessary to facilitate the development of viable business models for hydrogen projects. Hence, this study endeavours to fill this gap by shedding light on this overlooked aspect of the discourse.

Why can H_2 projects fail, i.e. not being implemented?

Meanwhile some large scale H2 projects in Germany have been cancelled (e.g. Westküste, 2023). The reasons for this have been gathered and are presented below in condensed form:

- Lack of Business Case: Financial viability is a critical aspect of project feasibility. Insufficient funding, budget overruns, and lack of investment, unclear value of green hydrogen leading to uncertainties in investment returns and operational sustainability.
- Technological Risks and Uncertainties: Hydrogen projects often involve innovative technologies with inherent risks and uncertainties. Failure to address technological challenges, such as scalability, efficiency, and reliability, can derail project feasibility during screening stages.
- Supply Chain Disruptions: Hydrogen projects rely on intricate supply chains involving production, storage, distribution, and utilization. Disruptions in the supply chain due to logistical challenges, material shortages, or geopolitical factors can disrupt project timelines and increase costs, impacting feasibility assessments.

- Policy and Regulatory Barriers: Complex regulatory frameworks, ambiguous policies, and inconsistent government support create obstacles for hydrogen projects. Uncertainties surrounding subsidies, carbon pricing mechanisms, and energy market regulations undermine investor confidence and project feasibility.
- In some cases, depending on the location also environmental aspects tend to become important, such as water usage and land use, also emissions such as heat and oxygen into the atmosphere begin to be discussed and might hamper permission and approval processes

2.4.4. Results: Relevant regulatory policies for H2 Economy

This section introduces the regulatory guidelines and programs of the EU and Germany as far as they are relevant for understanding the findings in this study. The various policies, directives and regulations are affecting the business model designs; they significantly impact the business models' viability and have been categorised as important elements for the business model designs. As a disclaimer, it is stated that it seems impossible to present and explain all funding programs or roadmap initiatives related to hydrogen, as there are numerous programs on the EU, national, and regional levels in Germany. Therefore, only those programs and guidelines that have been mentioned by the participants of the study are presented in the following.

This section has been updated as of the end of 2023 to reflect the current status of the directives and guidelines. However, despite the author's best efforts, it is important to recognise that no claim to completeness and correctness can be made, as the regulatory framework for the hydrogen economy is a "work in progress" for EU and national governments. What should be critically noted here is that the complexity and the lack of clarity regarding which policies are in force or still under discussion were also noted by the participants as major issues.

Green Deal, RePowerEU, Net Zero Industry Act

These programs outline the EU's goals related to climate protection, energy transition, and energy independence. They also legitimise several binding directives and quota regulations.

The European Green Deal (EC, 2023d) was presented first in 2019; it is a comprehensive plan initiated by the European Commission to achieve climate neutrality in 2050. It includes various initiatives to reduce greenhouse gas emissions, promote renewable energy, and improve energy efficiency. As part of this deal, the EU has set ambitious targets for reducing carbon emissions and increasing the use of renewable energy sources, e.g. the goal for 2030 is to achieve 55% less carbon emissions than 1990. The Green Deal includes several initiatives, some of which are briefly noted in the following.

The Fit for 55 package (EC, 2023d) was proposed in July 2021 and contains proposals to transform the energy supply in the transport and building heating sector to reach the 55% greenhouse gas reduction goal in 2030. The Net-zero Industry Act (EC, 2023f) aims to scale up the manufacturing of clean technologies in the EU; it was proposed in March 2023. Hydrogen technologies, such as electrolysers and fuel cells, are among those technologies that should be funded to be manufactured in Europe. The RePowerEU (EC, 2022b) program was launched in May 2022 and is a key component of the European Green Deal, focusing on reducing the dependency on

Russian fossil fuels, diversifying energy supplies and accelerating the deployment of renewable energy across Europe.

The programs offer vital support for the comprehensive advancement of hydrogen technologies, spanning research, development, and deployment, while also facilitating crucial infrastructure investments necessary for the widespread adoption of hydrogen as a prominent alternative fuel source. These initiatives serve as the driving force behind the formulation of legislative instruments, including directives such as RED II and RED III, which play a pivotal role in shaping the market dynamics for hydrogen, ensuring its viability and competitiveness.

RED II, RED III

The Renewable Energy Directive (RED) II and III are key legislative instruments within the European Union's framework for promoting renewable energy and reducing greenhouse gas emissions. With regards to hydrogen, the RED II (EC, 2023c) sets out rules for renewable hydrogen, which means defining rules under which conditions hydrogen is considered green and provides a methodology for the calculation of life-cycle greenhouse gas emissions. These RED II rules cover the hydrogen used for producing fuels (RFNBO, i.e. renewable fuels for non-biological origin). Since December 2023, these rules have been transferred to German law within the German laws for emissions (37. BImSchV) (BMUV, 2023), and they still need to be confirmed by the German parliament to be in force. Only after parliament has confirmed the law can the accountability of green hydrogen be reliably included in the business model design. Further acceleration in the energy transformation and further quota prescriptions are expected from the RED III directive (EC, 2023g) that entered into force on November 20, 2023. The EU member states have 18 months to transform the directives into national law. In summary, it can take more than 18 months until EU laws come into force in national states and provide regulatory clarity. These time spans need to be considered during project development.

ETS, CO_2 *pricing, EHB, Innovation Fund*

Further, EU instruments that increase the price for CO_2 emissions were mentioned by the participants as being important for the market design for ramping up the hydrogen economy. Thereby, the participants did not differentiate whether the regulations were already in force in Germany.

The Emission Trading System (ETS) (EC, 2023e) may be used to set a limit on CO_2 emissions in specific sectors or across the whole economy. The Emission Trading System (ETS) is a market-based mechanism designed to reduce greenhouse gas emissions by limiting the total emissions allowed within a specific jurisdiction. Under the ETS, companies are allocated or required to purchase emission allowances, which can be traded in a carbon market. This system creates a financial incentive for companies to reduce their emissions and invest in low-carbon technologies. However, IEA (2023a) reports that a price of USD 230 -550/t CO_2 would be needed to reach cost parity with hydrogen produced from natural gas, whereas the price has peaked at only USD 105/t CO_2 in 2023.

In March 2023, the EU announced plans to establish the European Hydrogen Bank (EHB) (EC, 2023b). The European Hydrogen Bank stimulates the production and use of hydrogen by reverse auctions, i.e., awarding financial support to the lowest bidder of renewable hydrogen. The plan is to bridge the gap between the prices of production and the prices the consumers are willing to pay for a 10-year off-take agreement, with a premium of up to EUR 4.5/kg H_2 (IEA, 2023a, p. 158). The first auction was launched in November 2023; the auction plans to close in April 2024 (EC, 2023a). The EHB is an OPEX funding instrument that can be combined with IPCEI CAPEX funding (EC, 2022a). The European Hydrogen Bank subsidies are financed from the EU budget allocated to the Innovation Fund (EC, 2022a) and by revenues from the ETS (EC, 2023e). Therefore, the European Hydrogen Bank has similarities with the much-praised US tax credit program within the Inflation Reduction Act (IRA) (USGovernment, 2022).

CCfDs, H_2 Global, EEG

The participants also mentioned a number of German-based policies and regulations as important for ramping up the hydrogen economy.

The H_2Global mechanisms (H2Global, 2023), originally a German initiative, is related to the European Hydrogen bank mechanism and uses a double-auction model. Instead of either subsidising the production price of hydrogen and paying subsidies to the hydrogen producer or subsiding the demand for hydrogen and paying subsidies to the consumer of the hydrogen to compensate for price differences between green hydrogen and hydrogen from natural gas sources, the H_2Global mechanism uses a combination of both. This means the lowest producer price offer for renewable hydrogen and the highest consumer price offer are matched, and the German government pays the price difference. The auctions are organised by a market intermediary called Hintco (Hintco, 2023); the intermediary will purchase the hydrogen from the cheapest supplier and sell it to buyers offering the highest prices. Currently, about 900 million euros are dedicated to the H_2Global mechanisms (H2Global, 2023) and joint auctions of the European Hydrogen Bank and H_2Global are being discussed (IEA, 2023a).

In June 2023, the German government unveiled the Carbon Contracts for Difference (CCfD) funding program aimed at bolstering efforts in climate protection (BMWK, 2023b). This initiative, akin to the EU's auction system facilitated by the European Hydrogen Bank, is designed to assist industrial firms, particularly in sectors like steel, cement, paper, and glass, in transitioning to environmentally sustainable production methods. Unlike traditional auctions, where bids revolve around monetary values, CCfDs introduce a novel approach: bidders compete based on the costs associated with averting tons of CO_2 emissions. Under this scheme, the winning bidder receives support from the German government to cover the additional expenses incurred over 15 years in curbing CO_2 emissions. However, the implementation of this program hinges on approval from the EU and is influenced by the recent decision of the Federal Constitutional Court, which deemed the German state supplementary budget unconstitutional and null (Bundestag, 2023). Consequently, the anticipated auction scheduled for the end of 2023 has been delayed. Despite these complexities, industry stakeholders view CCfDs as a promising tool in the fight against climate change, eagerly anticipating their rollout (see Chapter 6).

Also, the German Renewable Energies Act (in German EEG), the EEG 2023 (BMWK, 2023a), was mentioned as an effective instrument for the expansion of renewable energies in Germany. The goal is to increase the share of renewable electricity consumption to 80% in 2030 in Germany from today, 2023, 42%. The new version, the EEG 2023, furthermore promotes combining renewable energies with hydrogen-based electricity storage.

European Hydrogen Backbone, verifHy, Gas Transformation plans

Besides the funding incentives for green hydrogen supply and demand in order to create a market, the provision of appropriate hydrogen infrastructure, comprising logistics and storage, is very important, according to the participants, in order to be able to build viable business models. The development of the European hydrogen infrastructure, based on the existing grid for natural gas, is driven by the European Hydrogen Backbone initiative (EHB, 2023). The EHB published their initial report in 2020, and its activities to drive a pan-European hydrogen grid have intensified since the Russian invasion of Ukraine to increase independence in Europe from the Russian gas pipelines. Taking into account the typical project duration for a hydrogen grid transmission project, which is seven years (EHB, 2023), the feasibility studies have to start in 2023 in order to have the grid in operation in 2030. The European transmission grid will rely on repurposed pipelines as far as possible.

The infrastructure of the national hydrogen grid is even more important for the German hydrogen projects. These activities in Germany are driven by the DVGW (DVGW, 2023b), which is the association of the gas and water industry and also the recognised standardisation body for hydrogen grids. According to the Gas Transformation Plan (GTP), (DVGW, 2023a) the DVGW expects large-scale feed-in of hydrogen in the gas grids from 2030 onwards, mainly for heating and electricity generation purposes. The DVGW also creates a database that contains technical information about gas grid components; it can be used by gas grid operators to check the ability of their gas grid to transport hydrogen (DVGW, 2024) . In November 2023 a first draft of related hydrogen core grid laws was submitted to the government (BMWK, 2023d) that proposes, inter alia, the financing of the grid. The grid could be financed by grid fees that are capped at the beginning and deferred over time; in doing so future users also share the costs of building the network. The network operators will receive risk protection from the German government. The hydrogen core grid is planned to be operational in 2032. The first repurposed pipelines are planned to be operational in 2025 (BMWK, 2023d).

Critical remarks on regulatory framework discussions

This section offers a concise overview of the expansive regulatory framework surrounding hydrogen, currently under active discussion. While only those programs are introduced in this study that have been mentioned by the participants. It is important to acknowledge that numerous other initiatives exist within this landscape. The field is dynamic, as is evident from most references from 2023. However, the comprehensive discussions and intricate processes involved necessitate several years before EU regulations are implemented across member states. The complexity faced by stakeholders engaged in hydrogen projects is considerable and has even led to project cancellations, a sentiment echoed by some participants (see Part 2).

2.5. Answering the literature review questions

In this section, the findings from the literature review that contribute to the answer to the research questions are collated in a realist synthesis (Pawson, 2006; Tranfield et al., 2003). The following synthesis aims to generate a preliminary understanding of the research topic, "business model design for green hydrogen projects", and its underlying generative mechanisms, i.e. the correlation of the variables being relevant in the given contexts of climate protection and worldwide energy transition. In order not to get lost in the quantity and heterogeneity of the information available, the synthesis has been put together with the focus on what contributes to the answer to the research questions, following the advice of Pawson "What works for whom in what circumstances and in what respects?" (Pawson, 2006, p. 80).

The questions that were posed to the literature research are, what elements business models for future green hydrogen projects could consist of and, how these elements might relate to each other and interact. Table 2 and Table 3 compile the results that could be obtained from the literature research on these questions. Both tables organise the information with the help of design science frameworks, explained in Sections 2.2 and 2.4 and the CIMO logic, explained in Section 2.3.

RQ (1) What elements, drivers and parameters are potentially going to play a role in future business models for building green hydrogen projects?

The responses to RQ (1) have been meticulously crafted by extracting crucial concepts from the literature review on business model research. These concepts were then aligned with those outlined in the literature pertaining to green hydrogen generation. For instance, the impact of policymakers on fostering sustainable business models was explored. This qualitative analysis involved a thorough comparison of content to ensure coherence and relevance.

Then, the extracted key concepts are sorted and grouped to obtain a macro-level view (Foss & Saebi, 2017; B. Wirtz & P. Daiser, 2017; Wirtz et al., 2016) of the elements and concepts that could be important for designing successful business models for green hydrogen plants. This research investigates the creation of new business models for a new market, for a new company, hypothetically being equipped with ideal resources and organisational structures. Therefore, the analysis focuses on the external factors of the business model, such as customers and partners, and omits internal factors, such as human resources, cost structures of a company or managerial behaviours influencing business model innovation in real companies (Wirtz et al., 2016). Table 2 presents the results of the analysis, adapting the categorisations of Wirtz et al. (2016) and Di Tullio, Valentinetti, and Rea (2018). In Table 2 there are also labels proposed for the categories to link them to the design science approach, written in capitals in the column headings.

Table 2 RQ (1) elements and relevant concepts potentially driving BM for H_2 economy

BM dimension following Wirtz et al. (2016) OUTCOMES	BM elements potentially relevant DESIGN PARAMETERS	Relevant concepts and related activities INTERVENTIONS	Reference
Strategic – What are our strategic objectives?	• value proposition • key knowledge • key products & services	• aiming for long-term sustainability (preserve resources, take back, re-use) • aiming for social acceptance • being ready for interconnected BM	(Di Tullio et al., 2018), (Geissdoerfer, Pieroni, Pigosso, & Soufani, 2020), (Jocevski et al., 2020)
Customer & Market - Who are our customers, and what do we offer them?	• value proposition • relationships • stakeholders	Sustainable BM and Circular BM: ○ observe & reacting to the interplay of policymakers ○ observe & reacting to the perception of the public ○ observe & reacting to the perception of customers ○ assess the integration of customers in sustainable value creation Sharing BM Stakeholder management ○ accept a higher number of relationships ○ assess the levels and influence of relationships (regional, national, international) ○ assess value for stakeholders	(Di Tullio et al., 2018), (Geissdoerfer et al., 2020), (Centobelli et al., 2020)

Partners – Who are our partners, and how do we work with them?	• network model	• Network-oriented BM, interconnected BM (H_2 Clusters), business ecosystems ○ accept a higher number of relationships ○ assess the levels and influence of relationships (regional, national, international) • strategic networks	(Jocevski et al., 2020)
Value creation – How do we generate and deliver value? And to whom?	• value generation • value dimensions	• value networks, multidimensional value networks, business ecosystems • assess value creation through partnerships Ecological value creation: ○ sustainable value creation & capture ○ societal value creation & capture ○ destroyed value ○ missed value	(Geissdoerfer et al., 2020), (Centobelli et al., 2020; Jocevski et al., 2020), (Kraus, Filser, Puumalainen, Kailer, & Thurner, 2020)

Table 2 answers RQ (1) by giving a number of potential business model elements e.g. “value proposition”, “key knowledge”, “key products & services” (column 2, Table 2) and categorises the business model elements into business model dimensions, e.g. “Strategic”, “Customer & Market” (column 1, Table 2). Table 2 is therefore directly relevant for providing underlying theory for the data analysis in Part 2 of the thesis. Table 7 in Part 2 of the thesis presents the results of the analysed field data for the question of what elements future business models might consist of. Table 2 and Table 7, i.e. theory and practice, can be directly compared and discussed. This discussion and comparison is presented in Section 7.3 and Table 9.

RQ (2) What might be their (i.e., the business model elements') relationships, interdependencies, and mode of action?

Answers to RQ (2) were found by organising the available information in the CIMO logic (Denyer et al., 2008); the CIMO logic is introduced in Section 2.3 and revisited in Section 7.3. Table 3 maps the investigated topic into the CIMO logic, an initial understanding of potential relationships and potential underlying "technological rules" should be achieved. "C" stands for context; the context for the research topic is described as green hydrogen production, very large projects (mega-projects), climate goals and, in general ", energy transition". "I" stands for interventions, and "M" for mechanisms. An understanding should be developed of what the relevant mechanisms in place in the investigated topic are and which interventions could trigger those mechanisms. For example, the most obvious intervention in place is the injection of public funding money into the system (I1; Table 3). Through this intervention the mechanism is triggered to make projects financially viable (M1, Table 3), this leads to the realisation of projects (O1, Table 3) and therefore also to market growth which probably would not happen without that intervention. Another example would be that communication campaigns (I6; Table 3) would trigger the sermon mechanism (M6) and would probably create a higher public acceptance (O5). Of course, these interrelations are context sensitive, so I1, the injection of public money into the system, would not make sense if the context changes and climate change would no longer be a global objective for many governments. Table 3 shows the results of the synthesis. All the findings reference the studies summarised in Section 2.4.3; specific referencing has been omitted in the table for better readability.

Table 3 CIMO-synthesis of the green H_2 BM logic – towards an answer for RQ (2)

CIMO Component	Explanations relevant to the research topic (derived from (Denyer et al., 2008 ;Table 1)	Applied to the research topic
Context (C) What are the main variables from the context that potentially affect business model design?	Surrounding factors (internal and external), politics and power, nature of technical systems, uncertainty, system interdependencies, and other contextual layers (social system, infrastructural system, etc.)	• climate goals (C1) • EU and national H_2 strategies (C2) • maturity of electrolysis technology (C3) • costs of green H_2 production (C4) • public acceptance unstable (C5)
Interventions (I) What are the main interventions, and what mechanisms do they trigger?	The nature of the intervention and how it is implemented (e.g. leadership style, planning and control systems, performance management), also considering the hypothesis carried with interventions, e.g. "financial incentives will lead to higher worker motivation."	• injecting public funding (state aid) (I1) • ease regulatory framework (I2) • apply H_2 feedstock quota (I3) • rise price for CO_2 emissions (I4) • doing further R&D (I5) • communication initiatives about H_2 (I6)
Mechanisms (M) Which are the key mechanisms in place?	The mechanism that is triggered by the intervention in a certain context	• making projects financially viable (M1) • making projects technically viable (M2) • learning mechanism (M3) • carrot (incentives) mechanism (M4) • stick (punishment) mechanism (M5) • sermon (information, communication) mechanism (M6)

Outcome (O) What are the outcomes of the interventions?	The outcome of the intervention can have various aspects (e.g. cost reduction, performance improvement, etc.)	• projects are realised (market growth) (O1) • projects are sustainably profitable (O2) • technology is working properly (O3) • market demand is rising (O4) • public acceptance is improved (O5)

Table 3 works towards an answer for RQ (2) by informing about contextual topics that influence potential business models, e.g. the climate goals, maturity of technologies (row 1, Table 3). Table 3 furthermore informs about currently observable interventions, such as public funding programs (row 2, Table 3) and mechanisms, e.g. improved financial viability (row 3, Table 3) and outputs, e.g. rising market demand for green H_2 (row 4, Table 3) triggered by the interventions. Although Table 3 provides information on currently observable relationships in the H_2 economy, it does not answer RQ (2) as clearly and directly as Table 2 answers RQ (1). Nonetheless, Table 3, like Table 2 also provides underlying theory for the data analysis in Part 2 of the thesis. Table 8 in Part 2 of the thesis presents the results of the analysed field data for the question on how the business model elements are interacting. However Table 3 and Table 8, i.e. theory and practice, cannot be as directly compared and discussed as Table 2 and Table 7. Section 7.4 presents the discussion on theory and practice for the relationships of business model elements and their interdependencies to the contextual environment.

2.6. Developing the initial conceptual framework

The synthesis in Section 2.5, Table 2 and Table 3 presents the synthesis of the literature review. Table 2 presents a number of elements, dimensions and activities that are likely to be relevant for business models for green H_2 plants. Table 3 identifies some potential interrelationships and mechanisms revealed from the analysis of mostly non-academic literature in the context of green H_2. It must be said that both tables present information and analysis extracted from accessible literature; they do not claim to be complete nor to be "right"; they just help to get an initial idea of what kind of information might be expected from the fieldwork and what interdependencies might be in place, they, therefore, serve as initial propositions of what kinds of elements form the BMs and how they relate and act together. Furthermore, they help to set the level of detail and the perspective of how the BMs of the cases are planned to be investigated.

Building upon the foundational insights from the literature review, the preliminary concepts for the underlying conceptual framework have been built. This framework serves as a roadmap, directing the data collection efforts and later guiding the analysis and presentation of findings. It delineates the scope of the research and establishes clear boundaries, laying the groundwork for effective data collection (see Section 4.4.2). By providing structure and focus during fieldwork, the conceptual framework ensures that the fieldworks remain aligned with the research objectives, helping to guide the outcomes.

The objects of investigation, various green H_2 projects, shall be viewed as activity systems, following the concept of Zott and Amit (2010) performing a number of purposeful activities in order to produce, sell and transport hydrogen. Zott and Amit (2010) describe the activity system to consist of design elements, which describe the system's architecture. Zott and Amit (2010) go on to cluster the design elements in the *content*, describing the activities performed in the business, *structure* describing the links and sequential order between the activities and *governance* describing who should perform the activities and where. In the case of H_2 production projects, in principle, several elements of content can be thought of, e.g., in addition to H_2, oxygen (O_2) and heat could also be sold. The governance could also be set up in various ways, e.g., the H_2 project could be run as a joint venture (JV) of several companies by a single company or by the consumer/customer of the H_2 itself. The activity system design framework of Zott and Amit (2010) also looks at the sources of value creation within the BM, called design themes. According to Zott and Amit (2010) value can be created by different design themes in a BM, e.g. by *novelty*, i.e. some innovative design elements within the BM, either in content or structure or governance. A design theme can also include a *lock-in* strategy; lock-in means the customer cannot easily change the supplier. In the case of H_2 production projects, maybe long-term H_2 delivery contracts with the consumers of the H_2 can be considered as lock-in. Further design themes of Zott and Amit (2010) are *complementarities*, i.e. the bundling of activities to generate more value and the design of the BM for more *efficiency*, be reorganising activities to reduce costs within the BM. Establishing an online shop instead of selling only in a store would probably be an example of the latter. The data collection plan shall urge the collection of information about the design elements and design themes of the investigated cases. The information thus gathered can then be compared and analysed between the cases, and it can also be compared with the high-level design elements extracted from the literature research, synthesised in Table 2.

The conceptual framework for the data collection and even more for data analysis is also informed by the approach that Casadesus-Masanell and Ricart (2010) present in their paper “From Strategy to Business Models and Onto Tactics”. Drawing on the explications given in Section 2.4.2 the Casadesus-Masanell and Ricart (2010) framework is used to investigate ‘the logic of the firm, the way it operates and how it creates value for its stakeholders’ (Casadesus-Masanell & Ricart, 2010, p. 197, citing Baden-Fuller, MacMillan. Demil and Lecocq). Casadesus-Masanell and Ricart (2010) investigate the design logic of BMs by analysing ‘choices and consequence’ that form the BM and the feedback loops those choices and consequences create. The following clipping of the Ryan Air BM is taken from the Casadesus-Masanell and Ricart (2010) paper, p.199 and is used to explain the idea.

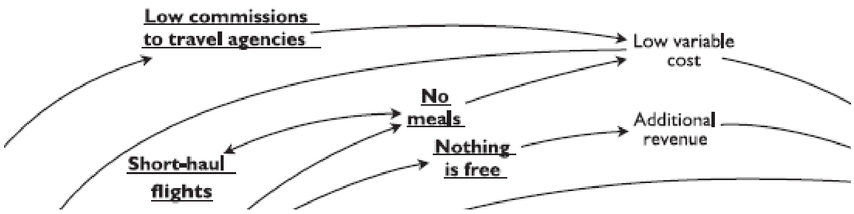

Figure 8 Clip from Ryanair BM analysis (Casadesus-Masanell & Ricart, 2010, p. 199)

Figure 8 illustrates Ryanair's strategic decisions regarding its business model, emphasising key choices through underlined and bold notions and their resultant consequences. For instance, the airline opted for short-haul flights and eliminated complimentary meal services, effectively reducing variable costs. Additionally, they implemented a policy of charging the customer for all services, significantly boosting additional revenue streams. The Ryan Air business model development and the choices available and the selections made have been an inspiration developing the conceptual business design models for the H_2 economy presented in Part 2 of this study. Leveraging the framework developed by Casadesus-Masanell and Ricart, allows to delve deeper into the generative mechanisms behind these decisions and the operational strategies that underpin them.

The initial conceptual framework primarily aims to facilitate and focus data collection and analysis; it is a merge of the frameworks of Zott and Amit (2010) and Casadesus-Masanell and Ricart (2010). The idea of design elements and design themes of Zott and Amit (2010) is used to identify the elements being present in the BMs and the underlying mechanisms of value creation. The idea of choices and consequences and feedback loops of Casadesus-Masanell and Ricart (2010) is used to investigate interrelationships, dependencies and sensitivities of the BMs, in other words, the business logic.

The following diagrams illustrate the initial conceptual frameworks, investigating the design elements and their correlations. The investigation for **Content** (Figure 9), i.e. to investigate which activities have been chosen (blue boxes) to be performed in the green H_2 project and the exploration of the consequences (light brown boxes) that such choices have, is considered to be most relevant for the research objectives. If possible, i.e., if such information is available, the design themes (green boxes) informing about the source of value creation for the related activities are also explored.

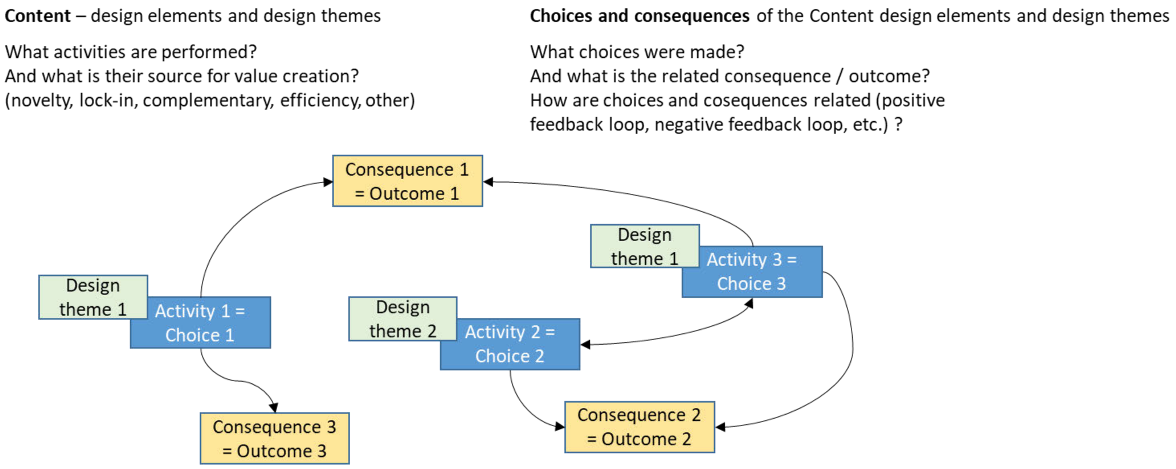

Figure 9 Initial conceptual framework – investigation of Content (author's own)

When faced with intricate and challenging business models, it can prove beneficial to analyse the additional design aspects highlighted by Zott and Amit (2010), namely structure and governance, in isolation. Figure 10 and 10 serve as visual aids for these frameworks, with explanations like those provided for Figure 9.

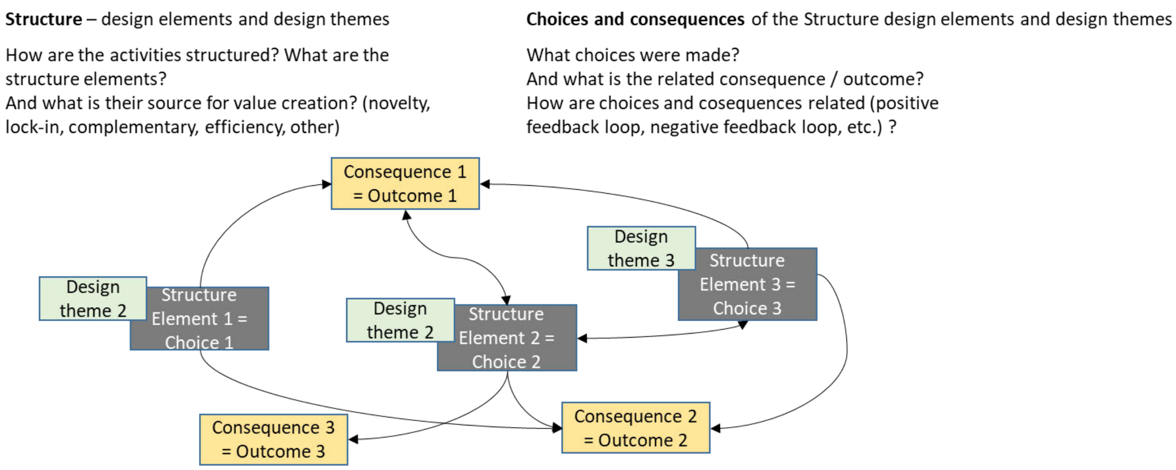

Figure 10 Initial conceptual framework – investigation of Structure (author's own)

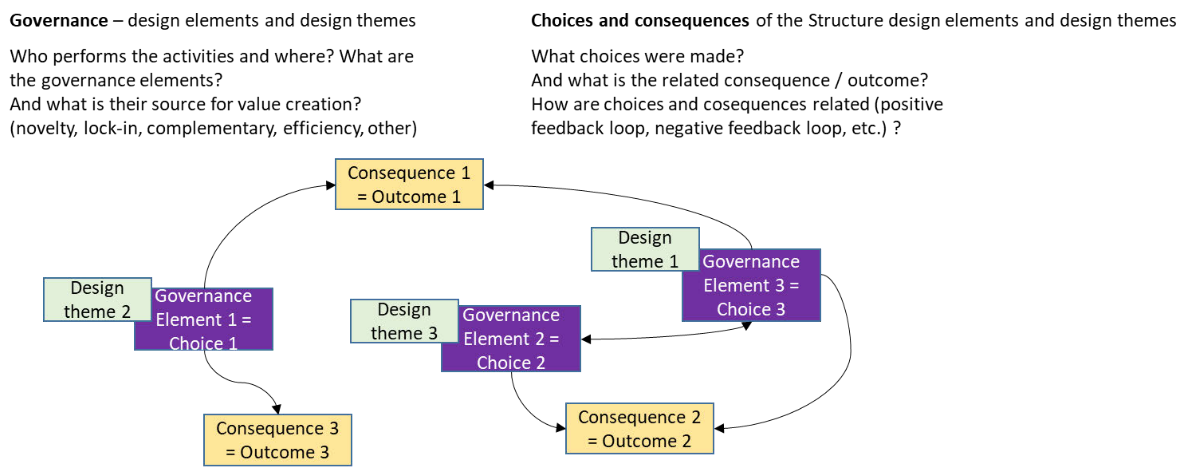

Figure 11 Initial conceptual framework – investigation of Governance (author's own)

2.7. Reflection, limitations and critics

The methodologies employed for this literature review encompassed an initial scoping review, an umbrella search, deep dives into selected meta sources and deep dives into the core articles. The review was further expanded by searching along several streams starting from the core articles (see 2.3 for further explanation). While the combination of these techniques aimed to ensure a comprehensive exploration of the research field, there are potential weaknesses and limitations that are acknowledged below. These may include the possibility of overlooking relevant studies despite thorough search strategies, potential bias in the selection of core articles for snowballing, and the inherent subjectivity in determining the scope and focus of the review. Additionally, reliance on a limited number of core articles for snowballing may introduce a degree of narrowness in the sources considered, potentially excluding valuable insights from other relevant studies.

Furthermore, it is acknowledged that various approaches could have been pursued to address the research topic. The specific research questions chosen for this study were carefully selected based on their alignment with the objectives of exploring broader business modelling concepts within the H_2 economy in a holistic way and not narrow the research down to single companies or single products. This focus necessitated the exclusion of literature reporting on a single product within the H_2 economy or reporting on a single company within the H_2 economy, as it would have diverted attention from the overarching goal of examining business modelling practices in a more comprehensive and holistic manner.

Using the method of a systematic literature review, posing literature review questions and developing an a-priori conceptual framework could be criticised as being too prescriptive for this exploratory research; it could be argued that an open approach would also be suitable and leave more room to discover new and unexpected findings (Vaughan, 1992). In the course of the study, the frameworks have helped to guide and frame the fieldwork but have never been used as fixed prescriptions; inductive elements for data analysis are included in the study design (see Chapter 4).

The hydrogen industry is developing very rapidly; a systematic approach, documenting search terms and sources and the time of the queries, helps to compare the developments over time. This was done to some extent in the Section 2.4.4. when comparing information from the initial literature review at the beginning of the study with those from the update at the end of the study.

Relying on grey literature, such as government papers and institutional reports, introduces potential vulnerabilities from potential inaccuracies. The field of green hydrogen is characterised by its dynamism, with a constant influx of both academic and non-academic contributions that have the potential to reshape the discourse swiftly. Although efforts were made to update the literature review towards the study's conclusion (late 2023 or early 2024), it is important to acknowledge that certain information may rapidly become outdated or incomplete. Hence, considering the evolving nature of the subject, it is crucial to contextualise findings temporally.

Overall, combining systematic review methods with targeted searches for specific articles through cross-referencing and snowballing has been effective for this research.

2.8. Concluding the chapter: The need for additional research

The literature review has revealed that no business modelling framework or concept or business model building blocks are available for green hydrogen projects. What it takes to design business models for large green hydrogen projects in Germany seems not to be well explored or not explored at all; at least, it is not understood. Such knowledge acquired by the actors in the hydrogen economy could advance the market ramp-up, which is supported by grey literature sources (e.g. TRANS4REAL 2023).

The literature reviews also revealed that only a few concepts on macroeconomics impacting business models are available. The need for additional research on the external influences on business models is also seen by Centobelli et al. (2020), Wahyono (2018) and Demil and Lecocq (2010).

Di Tullio et al. (2018), Musulin and Strahonja (2018) and others have called for more industry-specific terminology when describing business models. This study enquires project actors about their projects' business models. Thus, it ensures that the idiosyncratic terminology of the hydrogen industry will be considered in the developed frameworks.

Today, this study's topic is a white space in academic business model literature. Additional research in many directions can help to build up knowledge with regard to business modelling for hydrogen projects.

Research is not solely characterised by the sheer volume and comprehensiveness of information on a given topic. Equally important is how the researcher engages with the subject matter. As Bryman and Bell (2015) aptly point out, it is about the researcher's perspective on the world and their approach to gathering information. The upcoming chapter unfolds the foundational research philosophy, elucidating and rationalising the chosen methodology.

3. Philosophical background

3.1. Introduction to the chapter and the relevance of research philosophy

The chapter starts by explaining why philosophy is important for research, then briefly discusses the main research paradigms before delving into the critical realist and systems theory approach underpinning this study. The chapter concludes with some reflections on alternative approaches and a summary of the concepts that ground this study.

Research aims to generate knowledge in a specific field, but how this knowledge is acquired can vary. It depends on the research field's traditions, the problem's nature, desired outcomes, and other external influences. The researcher's philosophical position, worldview, beliefs, values, and experiences also play a role (Bryman & Bell, 2015; Easterby-Smith et al., 2018). A clear understanding and conscious choice of philosophical position are essential for conducting and evaluating research. Researchers must know their position to design coherent research that aligns with their worldview and produces credible results (Easterby-Smith et al., 2018; Gray, 2013).

Understanding the methodology and interpretation behind research findings is crucial for of research and for reviewers alike. It allows for meaningful correlation with existing research within the field (Easterby-Smith et al., 2018; Gray, 2013). Knowledge about a particular topic can be acquired through many methods and perspectives. For instance, one may choose to adopt a company-centric approach by conducting interviews with managers regarding the prospect of entering a new business sector. Alternatively, researchers may explore the broader societal and environmental implications by administering questionnaires to gauge social acceptance and attitudes towards CO2 reduction strategies.

3.2. Major research paradigms

Different approaches to research create different insights and leave different blind spots regarding the investigated subject. Daigneault (2013) illustrates these phenomena with the tale of the six blind men investigating an elephant (see Figure 12). Each of the men feels different parts of the elephant and consequently draws different conclusion about the appearance of an elephant. This metaphor is a reminder that research data might deliver only partial knowledge about a topic and might also come up with false conclusions as a whole.

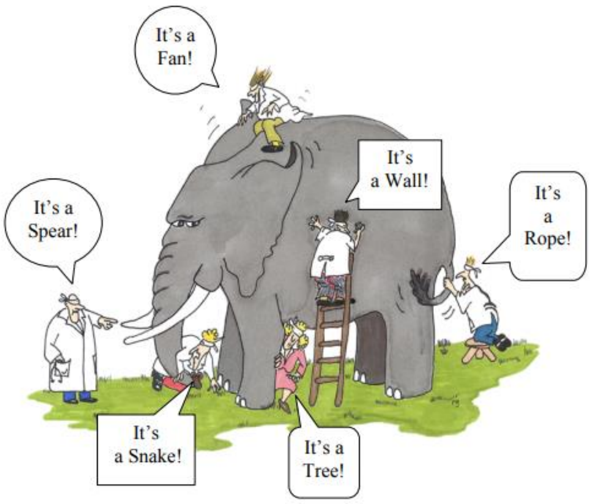

Figure 12 Investigation of "truth" by different researchers (Daigneault, 2013, p. 83)

Kuhn (1970), an American philosopher of science, was one of the first to elaborate on different traditions of generating knowledge in science, calling them "research paradigms". Simplified, there are two extreme forms of paradigms: the realist/positivist paradigm, mostly applied by natural scientists and the nominalist/constructivist paradigm, mostly applied by social scientists. These paradigms significantly differ in their underlying research assumptions (Easterby-Smith et al., 2018; Saunders, Lewis, & Thornhill, 2019). Realism regards reality as existing independently from the observer, while nominalism regards things coming into reality when created and named by observers (Easterby-Smith et al., 2018). Further, less radical paradigms emerged with the advent of applied science.

The study is nested in the field of business and management research. Business research is a relatively young academic discipline, drawing from social science, natural science, and applied science (Saunders et al., 2019). This diverse origin has sparked ongoing debates about which research paradigms to apply, about rigour and academic seriousness and the desired outcomes of business research (De Frutos-Belizón, Martín-Alcázar, & Sánchez-Gardey, 2019; Drnevich, Mahoney, & Schendel, 2020). Meanwhile, business and management research is seen as an applied science that contributes to theory and practice and applies moderate paradigms and a pluralistic approach (Easterby-Smith et al., 2018; Saunders et al., 2019; Tranfield et al., 2003).

Several moderate research paradigms are available, including post-positivism, pragmatism, and critical realism (Figure 13). In this study, a critical realist approach has been opted for, integrating elements of systems thinking based on Bhaskar's (2013) and Mingers' (2014) frameworks. This decision was made to ensure optimal coherence in the research design. Here, coherence refers to the alignment between the research field, the nature of the research, its purpose, and the researcher’s philosophical stance (Bryman & Bell, 2015; Easterby-Smith et al., 2018; Gray, 2013; Saunders et al., 2019).

3.3. Philosophical coherence in the study

Figure 13 gives an overview of the positioning of the major research paradigms and outlines their main underlying assumptions and values. Critical realism can be allocated to research in applied science, as business research is categorised as applied science; critical realism is, in principle, suitable for doing research in business research.

With its middle position between positivism and constructivism, critical realism is a moderate paradigm that allows flexibility and openness in the research design. The nature of the study is explorative; the topic is new and dynamic, and changes during the research had to be reckoned with. Critical realism allows multimethod and mixed methods (see Figure 13) and is flexible in its approach to theory development and thus seems suitable from this point of view as well.

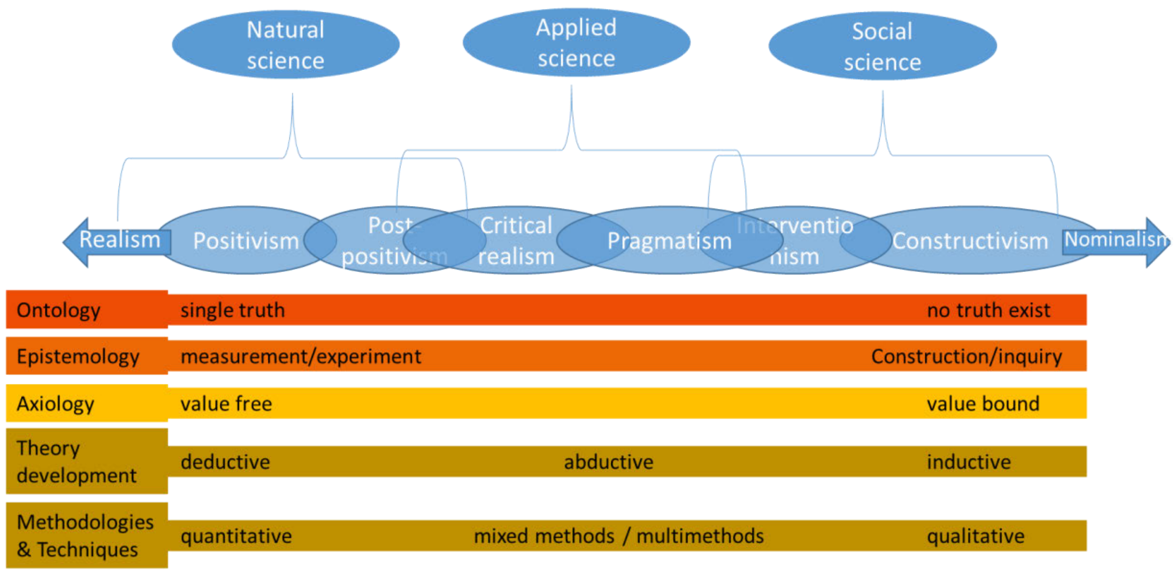

Figure 13 Major research paradigms and their philosophical positioning (compiled from Bryman & Bell, 2015; Gray, 2013; Saunders et al., 2019)

<u>Is critical realism also compatible with the researcher’s philosophical stance?</u>

The researcher, i.e., the author of this thesis, is an engineer in the energy generation industry with more than 30 years of experience, including more than ten years of managerial experience. The author leads a team of engineers executing hydrogen projects, e.g., engineering of electrolysis plants, construction of hydrogen refuelling stations, etc.

With a solid foundation in positivist paradigms commonly employed in natural and applied sciences, encompassing techniques such as variable reduction, isolation, experimental design, and leveraging established mechanisms as prescriptive theory, the researcher possesses a comprehensive understanding. However, it is the managerial experience of the researcher that has enabled also a nuanced perspective on the diverse truths derived from events and the myriad of realities individuals navigate.

The researcher's philosophical stance includes a realist view on ontology, believing that “real things” exist in the world and a relative approach to epistemology and therefore gathering various perspectives. Furthermore, the researcher strives for value-free, objective research; however, acknowledging that research results are influenced by current events and societal debates.

Moderate realism paradigms, such as critical realism, appreciate multi-level perspectives and aim to minimise bias while allowing subjectivity in findings interpretation to align with the researcher’s worldview.

The next section examines in more detail concepts of critical realism and related midrange theories, such as systems thinking, that contribute to the philosophical background for this research.

3.4. Key concepts of critical realism and relations to systems thinking relevant to this research

While all realist approaches share the same ontological understanding, i.e. that reality exists independently from the observer (e.g.Easterby-Smith et al., 2018; Gray, 2013), they differ in their epistemological and axiological assumptions and their radicalness towards those philosophical dimensions.

The key ideas of critical realism, expressed by Roy Bhaskar in many of his publications (Bhaskar, Danermark, & Price, 2017; Bhaskar & Hartwig, 2016) as the holy trinity of critical realism, outline the key beliefs of critical realism:

- ontological realism: reality is intransitive, i.e. the world, including all objects, exists independently from human perception, human knowing and scientific research
- epistemic relativism: human knowing is transitive, i.e. knowing is related to context, depending on the knower, perspectival and might be fallible
- judgemental rationality: the necessity to evaluate diverse and competing explanations to determine (relativistic) knowledge), so knowledge is a judgement made by the researcher

This understanding of knowledge and knowing impacts how the research is done, what data is collected, how the data is analysed and which logical chains of evidence are accepted as coherent explanations of the subject under investigation and which are withdrawn.

The study presents a concise overview of critical realism and systems thinking, elucidating their significance in the context of this research. Essential concepts from both fields are highlighted for clarity and ease of comprehension.

The study of the elephant in Figure 12 can be interpreted as a critical realist approach to research. Whilst the elephant exists in reality with a certain shape, size, and purpose, i.e. ontological reality is given, the knowledge that is created by the researchers in Figure 12 is relative and only partial, i.e. epistemological relativity is taking place, and the rational judgement made by the blind researchers in Figure 12, about what an elephant looks like, will likely be wrong.

Critical realism does not claim to achieve the real and complete truth about the investigated objects but strives to go for “the best explanation so far” (Mingers, 2014, p. 39). This approach was also chosen for this study. The findings and analyses in Part 2 best explain the study topic. The knowledge that could be acquired during this research has different forms and depths; not all aspects of “epistemological knowledge” can be achieved; sometimes only “propositional knowledge” or “performative knowledge” is gained. According to Mingers (2014, pp. 188-189) “epistemological knowledge” is the highest form that could be achieved; it means to know WHY something is happening. Other forms of knowledge and truth according to Mingers (2014) are e.g. “propositional knowledge”, i.e. to know THAT something is there or “performative knowledge”, which means to know HOW to do something.

Another group of key concepts and key ideas of critical realism and also of system thinking, are called multiple levels of reality, synonymously also stratification, laminated layers or hierarchically organised structures (Bhaskar et al., 2017; Bhaskar, Frank, Hoyer, Naess, & Parker, 2010; Mingers, 2014) are only partially illustrated by the elephant metaphor (Figure 12). The investigation of the elephant, as presented in Figure 12, only deals with its physical appearance, i.e. those features that can be directly observed and experienced, i.e. the empirical domain of that elephant (Bhaskar et al., 2017). Other “layers” of the elephant, what Bhaskar et al. (2017) termed the actual and the real domain, i.e. how the elephant acts and why the elephant does what it does, are not taken into account in Figure 12. Critical realism and systems thinking approaches would strive to investigate the elephant more holistically and try to get a systemic understanding of the elephant by learning about patterns that are not directly observable in order to be able to transfer the knowledge gained about this particular elephant to other elephants in similar contexts. That could mean that besides the elephant's physical appearance, its inner organism, its food, its digestive system, its habitat, and its social behaviour might become layers of the investigations.

The basic approach of a laminated investigation of different domains of an issue, e.g. the empirical, the actual and the real is illustrated in the centre of Figure 14.

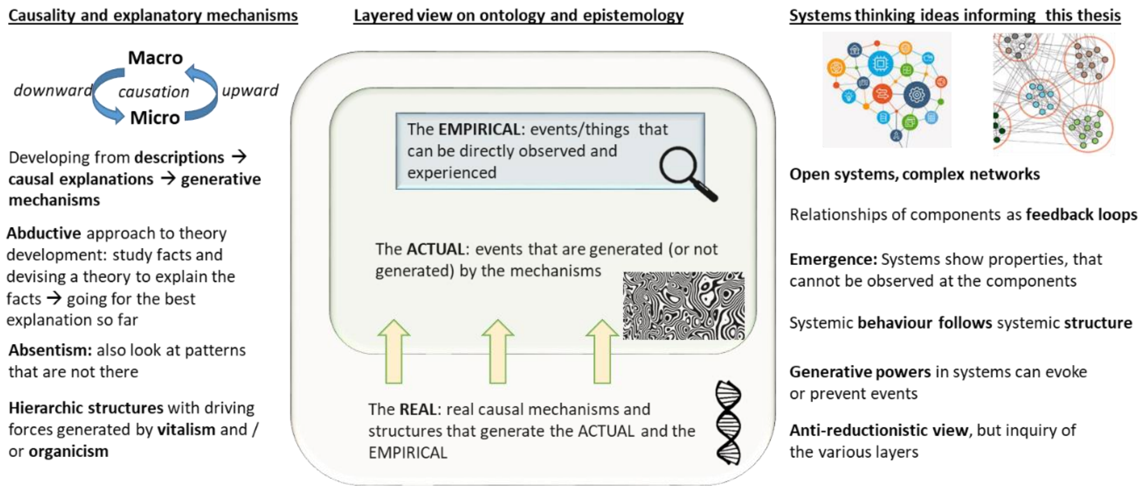

Figure 14 Key concepts of critical realism and systems thinking informing this thesis. (adapted from Mingers, 2014, p. 34)

The right and left areas of Figure 14 show further concepts that have informed this thesis, particularly the approaches to causality and theory (left area of Figure 14) and the ideas stemming from the systems thinking domain (right area of Figure 14). Those concepts have been extracted from recent publications of critical realism and systems thinking scholars (e.g. Bhaskar et al., 2017; Bhaskar et al., 2010; Bhaskar & Hartwig, 2016; Mingers, 2014) that engage with major problems of our time, such as global warming and social well-being. Those concepts encompass interdisciplinary inquiry into the behaviour of open systems and strive to identify general laws that remain valid for other similar settings in order to be able to predict tendencies. Outside the field of natural science, where experiment and isolating of variables are not easily possible, tentative statements, so-called demi-regularities like “x usually comes with y” and “rather x than y will happen” are desirable to achieve in the research (Archer, Bhaskar, Collier, Lawson, & Norrie, 2013). An <u>abductive approach</u> to theory development is taken, which means that the facts about a phenomenon are studied, and a theory that explains these facts as well as possible consequences is developed (Mingers, 2014). According to Bhaskar et al. (2017), the best explanation is found when holistic causality can be identified. This means coherence in causality is understood and simplified, which means that system structures co-determine the system elements and vice versa. This understanding also includes the acknowledgement of absenteeism and understanding the influence of powers and agents that might prevent the occurrence of a certain effect that normally, i.e. according to the generative mechanisms in place, would be produced (Mingers, 2014).

This research delves into examining business models for the green hydrogen economy. As detailed in Chapter 2.6, these business models are conceptualised as multi-layered activity systems. Moreover, they are acknowledged as open systems, given that not all parameters or variables of these business models are fully understood or feasible to study within the scope of this thesis.

Therefore, concepts that help to study open systems (see right area of Figure 14) also have influenced this research and are briefly discussed below.

"The whole is greater than the sum of its parts", simplified, this phrase describes the concept of emergence and means in practice that a system can have different properties and behaviour than the components that the system consists of, e.g. a car can drive, although none of its single parts can. The gaseous elements hydrogen (H_2) and oxygen (O_2) build liquid water, which behaves differently than its consisting elements H_2 and O_2 when occurring separately from each other as gaseous molecules. While the structure/composition of a system, i.e. the linking of the different components, is often unobservable, the systemic behaviour (=the ACTUAL) that is created by these causal relations (=the REAL) often is observable (Mingers, 2014). The kind of relationship amongst the elements of the system might become observable and evident in typical patterns of behaviour, such as linear causality ("x causes y") or circular causality ("feedback loops") (Mingers, 2014, p. 58). There are negative or balancing feedback loops ("more of x generates less of y") and positive or reinforcing feedback loops ("more of x generates more of y"). An example of a balancing feedback loop in the context of business models might be that "more green H_2 on the market lowers the price of green H_2". An example of a reinforcing feedback loop might be that "more public funding money leads to a higher number of projects to be implemented".

According to some scientists in the system thinking domain, the type of relationship between the elements is even more decisive for the system's behaviour than the elements themselves. As Werner Heisenberg, a well-known German physician, put it:

> In modern physics, the world is not divided into different groups of objects but rather into different groups of relationships … The world thus appears as a complicated tissue of events, in which connections of different kinds alternate or overlap or combine and thereby determine the texture of the whole (Heisenberg, 1963, as cited in Mingers, 2011, p. 306).

Different concepts for causality exist, depending on the research domain and traditions in paradigms.

The reductionist, deterministic approach propagates upward linear causation, which means there is a cause generating an effect on an upper level of the system. This is the traditional approach of natural science and is still often used in economics and management because this approach seems to break down complex issues into manageable chunks (Mingers, 2011, 2014). In contrast, the systems approach to causations acknowledges that there are non-linear correlations, which means that one effect can have many causes, and the other way around, one cause can have many effects. The effects can spread over several levels of the system, going upwards from macro to micro environment and vice versa going downwards, feedback loops can occur, and impulses and causes can also be nested in the environment, outside of the system (Mingers, 2014; Moellers, Bansemir, Pretzl, & Gassmann, 2017; Täuscher, 2018).

Those systems are often referred to as complex systems or complex networks, constituting a significant branch within systems theories (Bar-Yam, 2002; Bertalanffy et al., 1968). The concept of complex systems is not novel; as far back as 1948, Warren Weaver, in his seminal work "SCIENCE AND COMPLEXITY," categorised problems based on their intricacy. Weaver delineated "Problems of Simplicity," involving two or a few variables, as belonging to the 19th century, while "Problems of Disorganized Complexity," featuring billions of variables, were deemed characteristic of the 20th century, solvable through statistical mechanics (Weaver, 1948). Positioned between these extremes lies the "Problems of Organized Complexity," presenting a substantial number of variables—neither merely a handful nor billions—an intellectual frontier that science faces in the 21st century. Weaver illustrates this notion through the example of wheat price dynamics, a quintessential problem representing organised complexity:

> On what does the price of wheat depend? This, too, is a problem of organised complexity. A substantial number of relevant variables are involved here, and they are all interrelated in a complicated fashion but not in a helter-skelter fashion. (Weaver, 1948, p. 5)

Although the example of the wheat price is certainly out of date, parallels can be found that resonate with the H_2 economy. A considerable amount of variables are also involved, which are correlated over different layers of political, economic and technological influence. The connections are not in a helter-skelter fashion but somehow organised and embedded in an overall complex environment of decarbonisation and energy supply.

Amaral and Ottino (2004) define a complex system as

> A complex system is a system with a large number of elements, building blocks or agents capable of interacting with each other and with their environment. The interaction between elements may occur only with immediate neighbours or with distant ones; the agents can be all identical or different; they may move in space or occupy fixed positions and can be in one of two states or of multiple states. (Amaral & Ottino, 2004, p. 148)

The essence to convey is the perspective of considering the H_2 economy as a complex network system. By conceptualising business model design as interconnected activities within this network, insight into the causality and potential behaviour of such systems through the lens of network characteristics can be gained. This viewpoint is elaborated upon in the Discussion Chapter, Section 7.4.

Network analysts have developed a number of measures (Amaral & Ottino, 2004; Bar-Yam, 2002; Onday, 2016) to assess networks: For example, equifinality describes the principle that in open network systems, there can be many paths that achieve a given end state; for example, many paths are available in the internet for transferring messages, this path redundancy is a significant part of the stability of the internet. The number of nodes indicates the complexity of the system, and the number of direct contacts of one node indicates its importance, i.e., the centrality of the node.

Considering business models as open complex systems consisting of components and relationships, topologically organised on various layers, composed in certain structures, maybe networks, motivated by powers and agents is the underlying mind set of this study.

Although systems thinking and critical realism provide many more concepts for the inquiry of complex problems, the excursion into these philosophies is stopped here and Figure 14 is referenced again for a condensed view of the concepts that have informed this thesis.

3.5. Concluding the chapter: The paradigm choice and alternatives

The decision has been made for a critical realist approach combined with system thinking elements. Considering the multifaceted and interdisciplinary nature of the research topic, this approach appears to be the most suitable, leaving the appropriate flexibility to adapt during the research.

Potentially, a positivist approach could also be considered due to the researcher's technical background and the research topic's technical content. Such an approach could have involved modelling business cases in a quantitative Excel model to explore causal relationships between cost and revenue variables, for example. However, a positivist approach would not have been successful as the screening phase (Chapter 5) revealed a lack of reliable quantitative data and unstable conditions in the field, making predictions vague.

A critical realist approach emerges as a more fitting choice when considering the exploration of causality. While positivists and critical realists delve into causal relationships, critical realism's nuanced examination across different levels proves more adept for the intricate, interdisciplinary nature of the research at hand. Critical realism harmonises more seamlessly with the complexities inherent in this highly interdisciplinary field by rejecting the notion of absolute causality and advocating for exploration across multiple levels.

The next chapter discusses and justifies the research design, strategy, and methods applied.

4. The research design

4.1. Introduction in the chapter

The main purpose of this chapter is to present, explain, and justify the methodology and methods applied to this research and to present the research design. The chapter leads from the generic methodology and design to the specific methods and tools applied. It also presents how the design was put into practice. The chapter presents the quality criteria established in the design and the ethical considerations that apply to this research.

4.2. Overall research proposition and research questions initially and revised after the "screening phase."

The literature review revealed a scarcity of information about business models for the hydrogen economy, making this study exploratory. Exploratory study design must be broad and flexible, often employing qualitative methods to investigate issues. (Gray, 2013; Saunders et al., 2019). While open-ended research is possible, scholars recommend formulating initial aims and propositions to guide the study (e.g. Easterby-Smith et al., 2018; Gray, 2013; Miles, Huberman, & Saldana, 2014). According to these scholars, "What" and "How" questions are suitable for exploratory research, and "Why" questions can also be employed.

The research initially set out to explore established business model designs. However, due to a dearth of analysable models, the focus of the study shifted. Instead, it aimed to delve into the intricacies of business modelling activities within the H_2 economy. The central inquiry pivoted towards uncovering the optimal business compositions and associated operations necessary for the development of viable business models.

Table 4 shows the initial aim and proposition and the adapted one.

Table 4 Adaption of initial aim and proposition (author's own)

	Initial	Adapted after the screening phase
Aim	to investigate the suitability of existing business models for large-scale green hydrogen projects and develop recommendations for their advancement	**to investigate and understand business modelling for the H_2 economy**
Initial proposition / central research question	The present business model designs can be advanced and may help large-scale green hydrogen production projects to become viable.	**What business logic enables viable business models for large-scale green H_2 projects?**

The study was conducted in two phases: a screening phase to investigate the implementation status of German IPCEI projects and a main phase informed by the screening phase's findings. The next section will present the methodology and research strategy choices made for the study.

4.3. Methodology, research strategy and types of data

Having already determined that qualitative methods are suitable for this exploratory study (see previous section), the next question to clarify is which research strategy should be applied.

There are various research strategies available under a qualitative design, e.g. ethnography, ethnomethodology, cultural studies, grounded theory, narrative inquiry, phenomenology, action research, case study (Gray, 2013; Saunders et al., 2019), but those strategies focussing on the study of human behaviour can be quickly excluded as this is not the focus of this study.

A case study design was chosen to understand dynamics within single settings and investigate contemporary phenomena within real-life contexts (Eisenhardt, 1989; Yin, 2018).

Designing the study as participatory action research (Gray, 2013) in the author's company was considered but was deemed unsuitable as it would dilute the desired aim of enhancing knowledge about business model designs for the H_2 economy in general, not focused on a specific company.

In case study research, employing multiple sources of evidence is not just advisable; it is often deemed essential (Gray, 2013). Yin (2013) provides a comprehensive framework outlining six types of data - documentation, archival records, interviews, direct observation, participant observation, and physical artefacts - that can enrich case study investigations. In alignment with these recommendations, this study draws upon various sources of evidence. These include documentary research, survey data, interviews, direct observations, and contributions collected during conferences. Leveraging this diverse range of sources, aims to ensure a robust and comprehensive analysis of the subject matter.

Predominantly qualitative data has been collected and generated (Easterby-Smith et al., 2018; Gray, 2013; Miles et al., 2014). However, a small portion of quantitative data comes from a survey designed and conducted in phase 1 to broaden the study's database. Compared to quantitative data, qualitative data is rich in content; it is collected about the specific situation, it can be holistic and also bring along the meanings that are put to the case (Bryman & Bell, 2015; Miles et al., 2014). Qualitative data is potentially suitable to understand “latent, underlying, or nonobvious issues” (Miles et al., 2014, p. 11).

The case setting for the study are the IPCEI projects in Germany (BMWI, 2021a), which have high public awareness and receive public funding. Published data about these projects is available through various sources, such as web pages dedicated to public communication purposes. Project contacts can be found on these web pages, facilitating the recruitment of interview candidates for the main phase.

Semi-structured interviews were chosen to allow flexibility in discovering unexpected aspects during the interview process. Gray (2013) and Miles et al. (2014) propose a number of 6 to 15 interviewees as appropriate. For this study, 16 interviews were conducted, with information about the design and selection process for the interviewees provided in Section 4.4.4.

Focus groups were considered as an alternative method but ultimately not used due to challenges in organising and persuading relevant participants to join, although focus groups could potentially enhance generalizability and external validity by involving outsiders (Bryman & Bell, 2015).

4.4. Design of the case study and justification of choice

4.4.1. The basic design of the case study and the research questions

Although there is no prescriptive process on how to design a case study existing and some case studies, e.g. in ethnography following a grounded theory approach, are conducted completely without prior design (Yin, 2013), many authors in the domain (Eisenhardt, 1989, 2021; Seawright & Gerring, 2008; Yin, 2013) recommend to deliberately design the case study before conducting the research. Following those scholars' recommendations, a prior design has framed this research and has been a great aid for keeping the focus during data collection and analysis.

Yin (2013) outlines five essential components for designing a case study: (1) formulating clear research questions, (2) establishing propositions if applicable, (3) selecting appropriate case(s), (4) establishing a logical connection between the data and propositions, and (5) defining criteria for interpreting the findings. Following this guidance, the case study has been meticulously crafted.

The research questions and the propositions

After the screening phase, it was obvious that the research would be more exploratory than initially thought. Consequently, the research questions were adapted, and the initial propositions were dropped. A less tight design for the research was adopted. The screening phase was dedicated to finding out about the current status of the IPCEI projects; research question 0 and objective 0 guided phase 1, and research questions 1 to 3 and related objectives guided the main phase; see the following table.

Table 5 Research questions and objectives (author's own)

	Research question (RQ)	**Objective**
Screening phase	**RQ 0:** What is the implementation status of the German IPCEI projects?	**Objective 0:** To critically assess the implementation status of the German IPCEI projects
Main phase	**RQ 1:** What elements are the (future) business models consisting of?	**Objective 1:** To collect and critically evaluate the elements that compose future business models

	RQ 2: How are those elements interacting?	**Objective 2:** To critically explore the interaction and relationships of those elements
	RQ 3: What business model designs are considered today for upcoming large-scale green hydrogen projects?	**Objective 3:** To critically investigate the business model designs that are currently discussed

No explicit propositions have been formulated to avoid having a too tight design, that prevents from recognising unexpected findings (Vaughan, 1992) in this highly exploratory research. However, the formulated research questions and objectives implicate some underlying propositions, such as the existence of business model elements and the interaction of these elements. Eventually, the scholarly concepts of the business model literature have generated these underlying propositions, which are, in other words, underlying theories.

The case, the unit of analysis and the boundaries

The case is defined as a study of emerging business model designs for H_2 generation and H_2 infrastructure projects that belong to the German IPCEI projects. The unit of analysis is the business models, respectively, and the future business model designs within these projects. It can probably be argued whether these characteristics lead to a multiple case study or to a single case study with embedded multiple sub-units following Yin (2018) who distinguishes various types of case studies. Here, a decision has been made for the latter, i.e., this study is categorised as an embedded case study because the IPCEI program provides a joint frame for all the projects of interest to this study.

The IPCEI projects (BMWI, 2021b) serve as prime examples for the study, having undergone rigorous selection criteria set forth by the EU and the German government within the same timeframe. It is reasonable to assume that these projects share similar contexts and parameters concerning their goals and profitability. Consequently, it is also assumed that the individual projects within the IPCEI umbrella are subject to comparable business conditions. This assumption underpins the belief that utilising these projects will yield more reliable data and be conducive to producing valid results than a randomised selection of hydrogen projects in Germany for this study.

Seven of the 16 interviews have been with IPCEI project managers or similar important project roles. The selection for these seven projects has been made during the screening phase (see Section 5.3.2). The selection criteria were that the projects should either deal with H_2 infrastructure or with H_2 generation, the projects should be relatively far-developed, and the projects should have a certain degree of complexity. The other nine interview partners were selected to complement the view on the business models from diverse perspectives, such as science and politics for instance. Thus, the sampling strategy followed a systemic approach that is in line with the underlying paradigms of this study (Chapter 3) and also in line with a notation of diverse sampling strategies proposed in scholarly literature (Gray, 2013; Miles et al., 2014; Seawright & Gerring, 2008).

The boundaries of the case study design are, on the one hand, the IPCEI project program, as there is only data from IPCEI projects collected and, on the other hand, the period that the collected data is related to. In summary, the case study allows a cross-sectional glance at the business model design activities that took place from the beginning of the projects, i.e. the status and matureness they had reached when applying for the IPCEI program (Feb 19, 2021) until the time of the data collection period ended (August 2023).

The linking of data to the propositions/theories and the design criteria for interpreting the strength of the findings.

Basically, the design of the case study for analysis has foreseen both deductive and inductive strategy. For the deductive approach the data has been compared to theory (Miles et al., 2014; Yin, 2018), e.g. a number of a priori codes have been generated and later in the analysis the findings have been compared and contrasted with the initial conceptual frameworks elaborated in Chapter 2.6. For the inductive approach the data has been “worked from ground up” (Miles et al., 2014; Yin, 2018, p. 169), e.g. codes have been created in vivo allowing to discover what is in the data besides and in addition to the expected codes.

The chosen case study design includes the utilization of NVIVO for comprehensive data analysis. NVIVO efficiently tracks code references and file references, while also providing a wide array of features for data and code comparison. The quantity of references attributed to both codes and files serves as a valuable indicator of data relevance. Additionally, Section 4.6 elaborates on further quality criteria integrated into the study's design.

Which data to collect?

The purpose of a research design is to plan a systematic and structured approach before conducting the research to ensure validity and reliability and also to increase the chances to obtain meaningful results. In the case of qualitative research, it is in particular important to pre-plan data collection as it is a common pitfall of qualitative research to collect inappropriate data (Bryman & Bell, 2015; Easterby-Smith et al., 2018; Gray, 2013). Collecting too few or too much data or data that is, in the end not useful to answer the research questions and might even endanger to achieve the aim of the research is to be avoided and should be, in the best case, already be anchored in the design of the study (Bryman & Bell, 2015; Easterby-Smith et al., 2018; Gray, 2013). The study research questions, the objectives and, in general, the underlying theories and frameworks developed in Chapter 2 in the literature review, point to the kind of information that is needed to perform a good study, so decision has been made for this study to systematically scrutinize these items to extract the types and kinds of information that is needed to answer the research questions.

Mind mapping technique has been used to brainstorm about the question “what information is needed to answer the research questions”? In several brainstorming sessions, this question was asked referring to the gathered literature (“Which answers could be gathered in literature?”), referring to the two main underlying academic frameworks (“Which answers could be gathered in the frameworks?”) which were Zott and Amit (2010) and Casadesus-Masanell and Ricart (2010) at the time of the design of the study and this question was asked referring to the IPCEI project candidates (“Which answers could be gathered in the projects?”). This exercise has led to four mind maps providing information on which data should be collected, Figure 15 shows a screenshot of those mind maps, to give the idea on what they look like. Figure 15 is difficult or impossible to read due to its size. However, the legibility of Figure 15 is not important, as it is only intended to convey the impression that the mind maps helped to focus the data collection on the research questions.

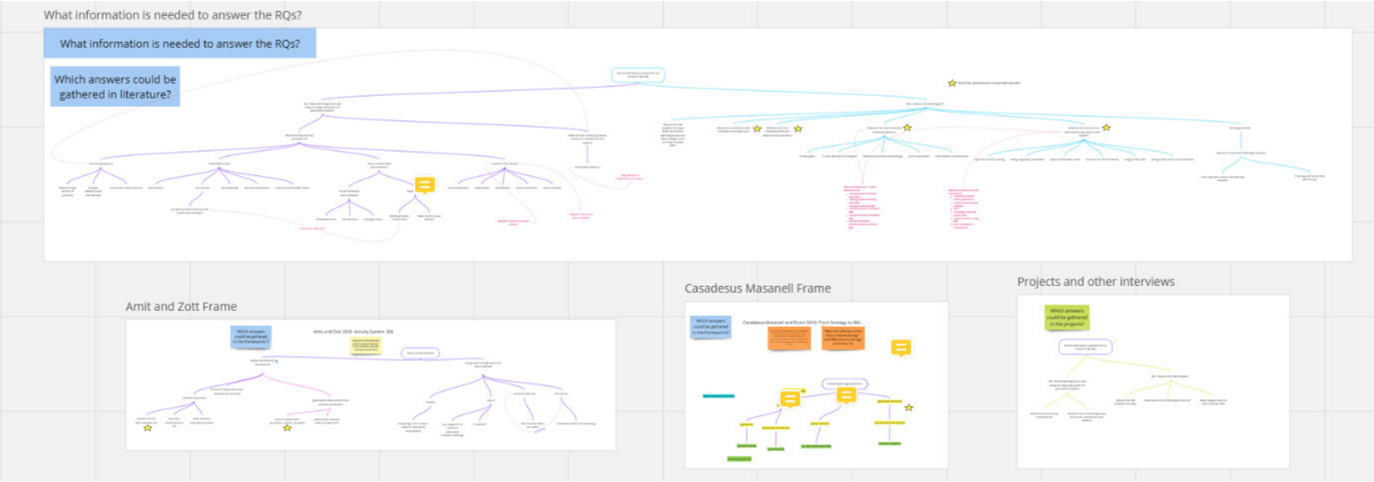

Figure 15 Screenshot "Information mind maps" – which data to collect? (author's own)

These information mind maps contain the information that is desirable to know (theoretically) to research the topic. The maps have informed the design of the survey and the design of the interviews, they also informed the a priori codes for the later qualitative data analysis. They have helped to stay focused during data collection and collect the information that was helpful.

Figure 15 captures the activities and outcomes of the basic design phase. It all began with a clear vision: to delve into the realm of business models for the hydrogen economy, fueled by the belief that enhancing these models could propel the advancement of the hydrogen economy itself. This vision paved the way for formulating the research questions, which in turn became the guiding light for the literature review. Through the literature review, crucial research gaps were identified and the initial groundwork for the study frameworks were laid. Recognising the potential pitfalls of qualitative research, particularly the risk of gathering irrelevant or insufficient data (Bryman & Bell, 2015; Easterby-Smith et al., 2018; Gray, 2013), a data collection plan was developed. This plan shaped the study into two distinct phases and served as the foundation for creating detailed information mind maps. These mind maps, in turn, informed the design of the surveys and interview outlines, ensuring that purposeful data is collected that is aligned with the research objectives.

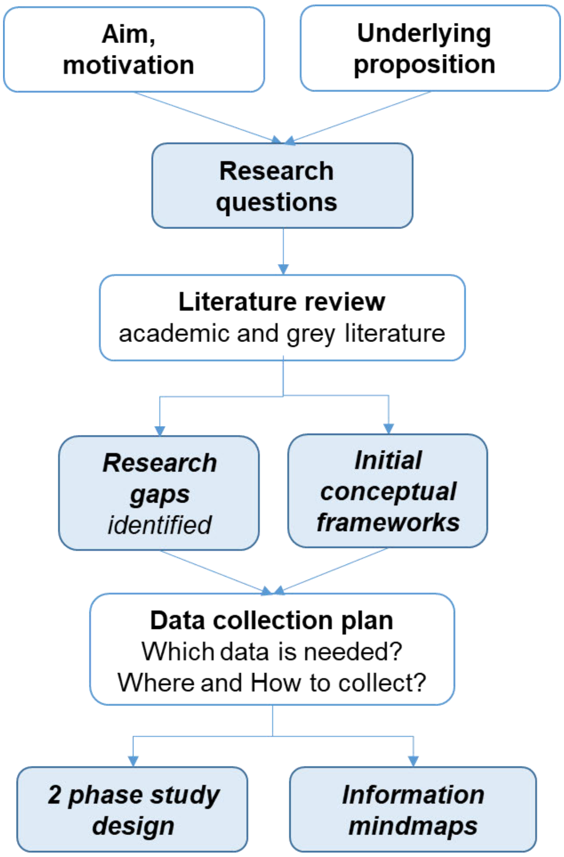

Figure 16 Basic design phase activities and outcomes (author's own)

The methods and tools for data collection that have been put in practice during the study, e.g. the survey design and the interview design, are described for the screening phase in Section 4.4.3 and for the main phase in Section 4.4.4.

4.4.2. Design choices for data collection, processing analyses and presenting

This section describes which features have explicitly been taken into the design, i.e. have been pre-planned, and how the methods and tools have been put into practice (survey design, interview guideline) is described in Sections 4.4.3 and 4.4.4.

Design of the case study protocols / interview preparations

Case study protocols were considered during the design phase of the study. Yin (2018) and other case study researchers recommend the use of case study protocols as a means to organise the research. The case study protocol outlines the line of inquiry, schedules data collection activities, gives guidance on preparing the collected data for analysis, and pre-plans the interviews (if applicable) and the case report. Case study protocols anticipate the information about the cases and collect every piece of information about the case; they are individual for each case. Having started to develop case study protocols for the project cases, this activity was stopped when it was realised that the projects and their business models were less developed than expected and, therefore, extensive case study protocols would not be needed and an individual, good preparation of the interviews will fulfil the task better than formalised case study protocols. Hence, all interviews were prepared individually, and already available information about the related project or other topic of investigation (e.g. research, politics) was collected in advance in order to be able to use the interview time as effectively as possible to collect new data and not waste time with information that could be gathered elsewhere. Individual questions were developed to collect specific information that only this individual interviewee would have. In essence, the interview outlines prepared for each interview were a mix of a case study protocol and the standard interview questions, which were asked similarly to all interviewees, and specific questions only asked the individual interviewee.

Type of the interviews

Interviews are a very common research technique in qualitative research, as they provide primary data, i.e. data that is explicitly generated to address the research topic and answer the research questions (Easterby-Smith et al., 2018; Gray, 2013). For case study research, Yin (2018) even sees them as “one of the most important sources of case study evidence” (Yin, 2018, p. 118). Interviews with project participants and other stakeholders have also been considered a suitable research technique to gather primary data for this study, as it was anticipated that people involved in the project have the desired information and like to talk about their work and share that information. Interviews in qualitative research come in different types and can be conducted in different ways. There are structured interviews, which follow a strict list of questions on the one end and unstructured interviews related to a topic or an event with no pre-planned questions on the other end. Interviews can be conducted via phone, online, or face-to-face, involve one or more persons and can be accomplished in one session or spread over several sessions (Easterby-Smith et al., 2018; Gray, 2013).

From this variety of available approaches to interviews, the choice was made for semi-structured interviews, which means a guided but also open structure that allows flexibility during the interview. The topics to be addressed are pre-planned, but there is no predefined structure or questionnaire to be followed (Easterby-Smith et al., 2018). Although the interview outlines prepared a set of individual questions for each case, and each interviewee developed from what is known about the case and the interviewee before the interview took place, these questions were not asked in a predefined order nor were they asked question by question. The purpose of the questions was to be as prepared as possible, but they should not hinder the exploration of other unexpected information that might come up during the interview. In summary, the interviews were prepared but had a loose structure, following the need for information and allowing unexpected excurses to consider the study's exploratory character.

Although suggested by esteemed scholars such as Easterby-Smith et al. (2018) and Yin (2018), no pilot interview has been conducted for this study. This decision was made considering the extensive information gathered during the screening phase of the projects. Additionally, prospective interviewees were thoroughly briefed on the interview's content and purpose during initial phone calls, obviating the necessity for a pilot. Furthermore, for individuals desiring written preliminary information, a concise one-page information sheet was provided along with details regarding data protection and consent (refer to Appendix 2). It is important to note that the design and execution of the interviews have been intentionally kept flexible, allowing for adaptation both between interviews and during the interview process itself.

Most of the interviews have been conducted via MS Teams, some have been conducted face to face, and the interviews have been recorded and then transcribed to be analysed in NVIVO. The outline of the interviews and the conducting of the interviews in practice is detailed in Section 4.4.4.

When is data collection finished? – Sources of evidence

For qualitative research scholars advocate the principle of "theoretical saturation" (De Frutos-Belizón et al., 2019; Glaser, 1999; Pawson, 2006), this means to stop collecting interview data when no new information was obtained from additional interviews. Yin

(2018) advocates for case studies to collect evidence from two or more different sources for most of the main topics under investigation, which means the concept of multiple sources of evidence to enhance the quality of the research.

Both principles were carefully considered throughout the development of the data collection process. After conducting 16 interviews, despite the availability of additional candidates, the interviews were concluded as they no longer yield new insights.

The approach encompassed diverse sources, including document research, internet searches, governmental publications, surveys, observations, and engagements at conferences. The various conference contributions, such as panel discussions, presentations, and speeches were diligently documented and analysed, to ensure comprehensive coverage and depth in this research.

Data management and data processing

During the study, many files were created, downloaded or otherwise processed. Data management and organisation is a major task during the study that helps increase the quality and rigour of the research, when done properly (e.g.Easterby-Smith et al., 2018). The author’s laptop with the Microsoft Office installation and the other software installations used for the study (e.g. NVIVO, Unipark) has been used for data management. This laptop is only used by the author and protected by a password; unauthorised access is prevented. All data related to the study is organised in one folder and is regularly backed up. The audit trail, which allows data to be backtracked to the original file, has been respected. This means that the data is stored and processed in several collections. There is the raw data evidentiary base, such as the recordings of the interviews, the documents, the videos and recordings of the conferences etc. There is also the collection of the working documents during the study, e.g. the “IPCEI project list”, the information mind maps, the interview outlines, etc. Then there are the analysis and evaluations, the survey, the coding, and the literature review; these types of files are stored in the related software installations, such as NVIVO. The graphical concepts and illustrations have been stored in PowerPoint.

In qualitative research, it is widely accepted to conduct data processing and analysis concurrently with data collection (Gray, 2013; Saunders et al., 2019). This approach facilitates adapting and refining methods as necessary during the research process. For instance, if unexpected topics arise or initial research strategies prove ineffective and require adjustment, this method allows for such flexibility. In line with this approach, this research follows a similar procedure; for instance, while surveys were still being distributed to gather responses, initial interviews had already commenced.

Data analysis and presentation

For the purpose of completeness, various methods of analysis were used during the study. The survey for instance has been analysed by using the automatic reporting tool of the software (unipark.com), which prepared and presented the data using descriptive statistic, the full report is attached in Appendix 3

Furthermore, the 62 IPCEI projects have been analysed and grouped by pattern matching (Miles et al., 2014), i.e. the projects have been analysed by their similarities using Excel diagrams.

However, the main analytical task within this research is the analysis of large amounts of qualitative data from the main phase. A number of analytical techniques are available for qualitative research, e.g. content analysis, narrative analysis, discourse analysis, thematic analysis, grounded theory or interpretive phenomenological analysis (Bryman & Bell, 2015; Gray, 2013; Saunders et al., 2019). As the study objects are business models, those techniques that focus on the study of human behaviours or languages, i.e. narrative analysis, discourse analysis and interpretive phenomenological analysis, have been discarded. Grounded theory has also been discarded, because although the study design has integrated inductive elements it also relies on theory and underlying conceptual frameworks. Therefore, content analysis (Mayring & Fenzl, 2014; Schreier, 2012) and thematic analysis (Braun & Clarke, 2006, 2021) were shortlisted as suitable analytical techniques. Comparing the two techniques, the author of this study had the impression that content analysis is more deductive, determining categories in data or the presence of certain words, content analysis seems to follow a fragmentary approach to reduce data. Thematic analysis seems to be more inductive. The themes are developed from the codes; they are generated by interpreting the data by the researcher in order to organise them to central underlying concepts (Braun & Clarke, 2021). The reflexive thematic analysis approach following Braun and Clarke (2006) has been chosen as the analytical technique for the main phase, as it seems to be systemic and inductive to rather aggregate data then fragmenting the data, which is also in line with the concepts of system thinking that are presented in Chapter 3.

This study employs a diverse array of methods to present its findings, tailored to the nature of the data and the depth of analysis required. These methods include illustrative quotes extracted from interviews, narratives that condense and integrate information, as well as tables, charts, thematic maps, and concept maps. Additionally, supplementary materials like codebooks, survey questionnaires, and reports are provided in the appendices. These supplementary materials serve to bolster the credibility and rigour of the study's assertions.

4.4.3. The data collection, processing and analysis in practice phase 1, "screening phase."

Design and purpose of phase 1 "screening phase" in practice

The purpose of the screening phase was to find out about the actual IPCEI project situation, how far the project development has progressed, what has happened since their launch and whether there have been major changes since the launch of the projects. Figure 17 shows the three activities undertaken in the screening phase and the three main outcomes that were to be and were achieved.

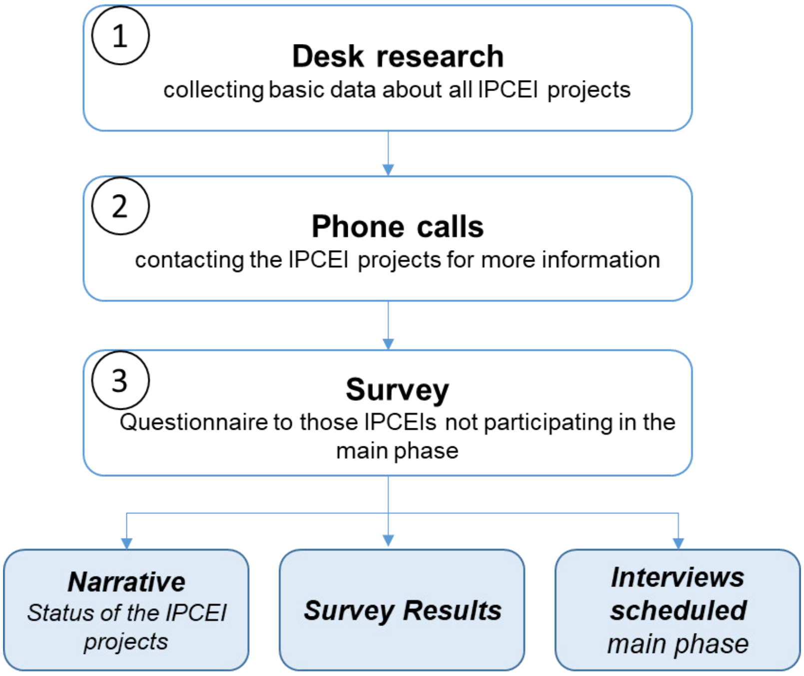

Figure 17 Screening phase activities and outcomes (author's own)

The screening phase was initiated with thorough desk research to gather pertinent information regarding the IPCEI projects. This involved combing information from various sources such as websites, press releases, governmental publications, and company announcements. The collated data was meticulously recorded within an

Excel spreadsheet dubbed the "IPCEI project list" (refer to Figure 20), which functioned as the primary database throughout the data collection process.

The desk research was crucial to identify contact persons, collect basic project information, and pre-select interesting projects and other informants for the main phase of the study. The next step was to call the project actors to gather first-hand information about the actual project status. During the phone calls, the questionnaire was also announced, and if the project was an interesting candidate for the main phase, the willingness to give an interview was ascertained. The outcomes planned for the screening phase were all achieved: to have an actual status of the IPCEI projects, to have gathered the survey from those IPCEI projects which do not take part in the main phase and to have the interviews for the main phase scheduled (see Figure 17).

Developing and testing the questionnaire for the survey

Generally, survey methodologies are rather assigned to descriptive and explanatory research than to exploratory research (Gray, 2013), but can also be used in qualitative research and in particular in case study research strategies in order to diversify the sources of evidence (Saunders et al., 2019; Yin, 2018). The general design of the questionnaire followed the advice given by many scholars of business and management research (e.g.Bryman & Bell, 2015; Gray, 2013; Saunders et al., 2019): length of the questionnaire below six pages, clear and interesting presentation of questions, easy to understand and fill, pilot tested to ensure appropriateness and comprehensibility. After drafting the questions in paper format, the decision was made to use web-based survey software, as survey software offers support in creating questions, survey design, survey management of respondents, automated survey evaluation, etc. There are many survey software tools available, finally Unipark online survey software (unipark.com) was preferred over SurveyMonkey, GoogleForms and others, because Unipark is commonly used by universities and research institutes and offers scientific standards, Unipark is furthermore certified according to ISO 27001 standards for quality assurance and data security.

To facilitate reporting for this study, it was ensured that questionnaires and reports could be designed in multiple languages. In practice, the participants received the questionnaire in German, yet it is also available in English, as are the subsequent reports. This multilingual approach allows to maintain the original layout while ensuring accessibility in English, thereby enhancing the validity and authenticity of the research.

Before sending out, the questionnaire was tested in two steps. In the first step, family members and friends tested the questionnaire for typos, bugs and errors. Furthermore, it was tested on various devices, such as laptops and mobile phones. In the second step, the questionnaire was piloted and sent to four pilot participants who were knowledgeable in the field of hydrogen but not participating in the later research. The questionnaire was fine-tuned considering the comments and feedback from the pilot users, i.e. some questions have been revised, and new aspects have been added. The data given by the pilot users was also used to design the evaluation and automated report. However, the test data were deleted before launching the questionnaire.

In order to avoid the complex handling of the EU General Data Protection Regulation (GDPR) and also to ensure participants about the purposeful use of their data and to ensure them about confidentiality, the survey was set up as an anonymous query, where each participant uses the same link to the survey and no relation from the data to the participant can be drawn. The link was sent with an introductory email to the participants (see Appendix 2).

In this research, the survey methodology is used to collect primary data with the purpose of diving deeper into the field of research, exploring the current situation and sentiment and identifying themes of interest for phase 2 of data collection. Therefore, the interesting information to be drawn from the questionnaire is about the current status and progress of the IPCEI projects made since their selection in May 2021 (Figure 19) and about the environment of the projects. Having this focus, the data is evaluated and interpreted qualitatively, quantitative analysis, such as statistical analysis correlations, Cronbach's alpha coefficient (Saunders et al., 2019) is not of interest for this study.

In total, five subject areas, A) to E), with a total of about 15 questions, were designed. The questions are mainly to be answered in multiple-choice mode; some also have free text fields for additional information, and a few questions are ranking and rating questions. The subject areas are ordered in this way following the advice of scholars (e.g. Gray, 2013) to start and close with easy-to-answer questions and place the heavier part of the questionnaire in the middle section.

Appendix 2 presents the comprehensive questionnaire in English, maintaining the original German layout. The questionnaire's design and the types of questions featured within have been carefully crafted based on information gathered from the mind map, as sketched in Figure 15. These visual representations were instrumental in identifying the necessary information to collect in order to address the research questions. Furthermore, the selection of response options in the questionnaire has been informed by insights gleaned from both the literature review and the initial conceptual framework derived from it. Below is a succinct overview of the questionnaire's five subject areas labelled A) to E):

A) Your IPCEI project: products & services

contains questions about the products and services being produced in the project

B) Your IPCEI project: project progress

asks about the status of project development and the degree of satisfaction of the actor

C) Your IPCEI project: drivers & barriers

asks for a ranking of the current most important drivers and barriers

In this section, the participants could rank from a given selection the three most important drivers and barriers to the projects' business model that are currently perceived. For both questions, a free text field was available where the participants could add additional drivers or barriers or just additional information on the theme.

The lists of drivers and barriers were derived from insights generated in the literature review and complemented by information gained through the desk research. Participants had to select three drivers and respectively barriers from the lists and rank them per drag and drop on numbers 1, 2 and 3. For evaluating the answers, the number 1 ranked item was coded with 3 points, the number 2 ranked item with 2 points and the number 3 item with 1 point; all the items not selected as one of the top 3 received no points. The answers were evaluated by calculating the arithmetic mean value for all items.

D) The H_2 IPCEI projects in the context of current politics

asks for assessing the importance and relevance of several contextual topics for the roll-out of large-scale H_2 projects. A scale is given, ranking the importance between "rather unimportant" and "very important" for a number of contextual topics, covering governmental strategies, such as the climate goals of the EU, funding initiatives and regulatory guidelines. One question also asks how to assess the efficiency of the IPCEI project application process.

As highlighted in the literature review (Chapter 2.5), various factors, including the broader context, public interest, and political discourse, significantly shape the evolution of H_2 projects in Germany. This section of the questionnaire aims to gather insights into how the political landscape, including funding initiatives, legislation, and regulatory frameworks, is perceived by stakeholders involved in these projects.

<u>E) Conclusion and statistical information</u>

asks for the participant's role in the project and the IPCEI category to which the project belongs.

The questionnaire does not collect any demographic or personal data of the participants, such as age and gender, as the focus of interest is the situation of the IPCEI projects, which does not depend on participants' demographics or other personal data.

The survey was announced on phone calls, and a link to the anonymous web-based questionnaire was sent directly after the calls. According to literature, expected response rates for questionnaires are rather low. For web-based questionnaires, Saunders et al. (2019, p. 507) note a 'variable to low' response rate of '10% or even lower'. Because of the personal contact made before sending the questionnaire, the response rate for this questionnaire has been significantly higher, and up to 30 responses could be collected.

4.4.4. The data collection, processing and analysis in practice phase 2, "main phase"

Design and anticipated outcomes of phase 2 "main phase" in practice

The design of the main phase was slightly adapted based on what was learned during the screening phase. The data collection strategy has been broadened. In addition to the interviews with project participants, it was decided to conduct interviews with experts knowledgeable about the various external factors, i.e. finance, funding instruments, regulation, research, etc. Furthermore, relevant events, e.g. conferences, fairs webinars on hydrogen that took place during the data collection period were attended and contributions that contain relevant information were downloaded and also added to the database. Figure 18 shows the activities and outcomes of the main phase.

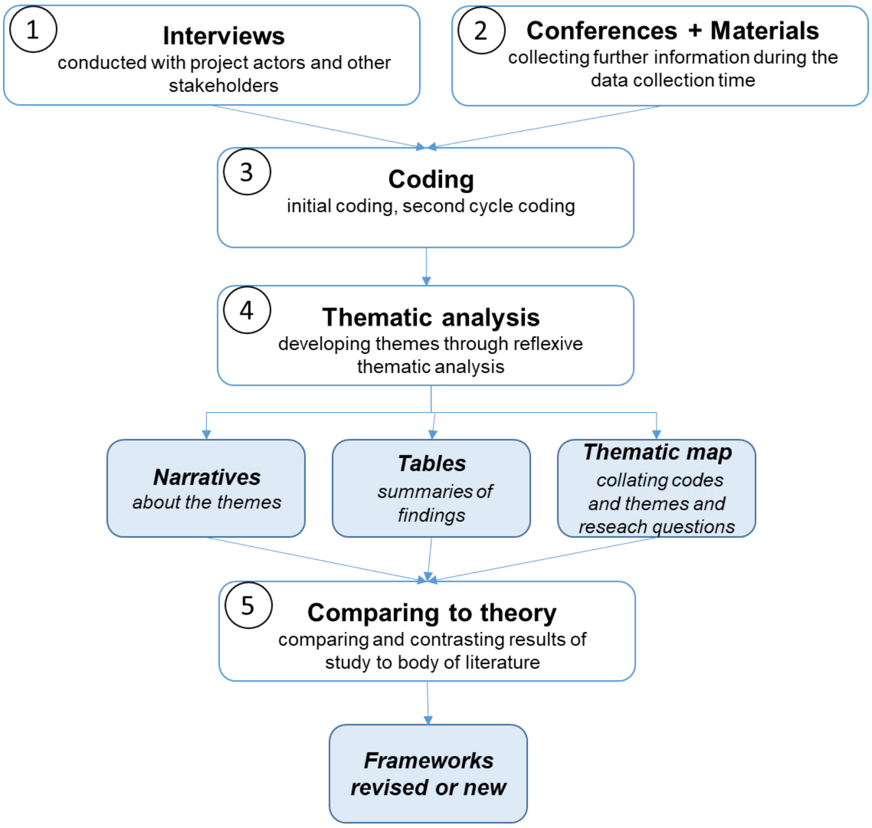

Figure 18 Main phase activities and outcomes (author's own)

The various sources of evidence have been qualitatively coded and then thematically analysed. As in reflexive thematic analyses “theme development requires considerable analytic and interpretative work on the part of the researcher” (Braun & Clarke, 2021, p. 39) it has been decided to describe this step within the findings and results, Section 6.2 and not in this research design section

The endeavours undertaken yielded the desired outcomes (refer to blue boxes in Figure 18), including the development of narratives encapsulating the core themes and succinct summaries outlining key findings, alongside the creation of a thematic map. Being capable to draw a thematic map within reflexive thematic analysis is important, as highlighted by Byrne (2021). Such a map serves as a vital tool in amalgamating the derived themes from the data with the research questions, elucidating the interrelationships among these themes. Subsequently, these findings underwent a comparative analysis with existing theories. This analytical phase aimed to ascertain whether established theories, such as business model frameworks gleaned from literature or the initial conceptual framework (refer to Chapter 2.6), were substantiated, or if novel frameworks emerged to better capture and articulate the findings compared to pre-existing ones.

Various sources of evidence have been collected.

The primary source of evidence for the study are the 16 interviews. The interviews have been conducted via MS Teams, except for one that has been conducted face-to-face; all were conducted in German language. Three of the interviews were group interviews where two or three interviewees participated. The participation of several interviewees in one interview was at their own request. They wanted to ensure that they are able to provide information on the different subject areas of the interview. Those group interviews have not been distinguished and documented as one interview. Seven interviews were conducted with project actors (project managers and business developers) involved in either H_2 generation or H_2 logistics projects. The results of the screening phase (Section 5.3.2, Figure 21) indicated that the complex, large IPCEI joint projects are the most interesting candidates for an interview because their business models are the most professionally developed compared to the smaller IPCEI projects that only develop one product. The projects were pre-selected during the screening phase, and the participants were accessed by phone. Further, nine interviews were conducted with consultants, financiers, politicians, and association representatives. These participants have been identified either during the review of the grey literature because they were authors of publications or because they were recommended by other interviewees as being knowledgeable in a certain area. All participants agreed to the interview being recorded but emphasised that the information must be anonymised and disguised so that no conclusions could be drawn about the person or the project. The interviews lasted between 19 and 80 minutes, an average of 44 minutes per interview. Appendix 4 shows the list of interviewees. The 16 transcribed files formed dataset 1.

The second dataset contains relevant presentations, speeches and other contributions at three hydrogen events that took place between March and July 2023. These conferences were attended by the author.

1) **FAU insights** - Great topics of the future are intensively illuminated. Hydrogen meets business - research meets practice (FAU insights). The FAU insights are a lecture series (26. April - 5. July 2023) organised by the FAU University of Erlangen – Nuremberg

The FAUinsights was a hybrid format; the sessions were broadcasted via live link, but it was also possible to attend the lecture in person in Nuremberg; the FAUinsights are in German language. Five contributions were selected because they contained relevant information on the need for action with regard to regulation, value chains, project financing, H_2 pricing and market development.

2) **H_2 Forum Berlin** - „Accelerating Europe's hydrogen economy now: joint forces for energy autonomy and CO_2 neutrality" (H_2-forum). The H_2 Forum is a yearly management conference that took place on June 6 and June 7 2023

The presentations and panel discussions have been recorded and made available for download to the conference participants. Eight contributions have been selected to hold relevant information for this study.

3) **VDV Electro Bus Conference Berlin** – The VDV conference (14th VDV Conference) is a yearly event, focussing on electro mobility and having forums and discussions about hydrogen mobility. The conference took place on March 27 and March 28, 2023. The presentations have been made available for download to the conference participants. Four presentations about hydrogen mobility projects have been selected and added to the database.

In total, seventeen video recorded speeches, panel discussions and presentations, about 4,5h of recorded material and seven conference presentations in pdf format formed dataset 2.

Throughout the interviews, several participants thoughtfully recommended supplementary sources of evidence, including various documents and reports they had prepared or accessed. Recognising the potential relevance of these materials to the research, each submission underwent meticulous screening. Five documents have been carefully selected from this process, all of which have been incorporated into the database. Together, these documents constitute dataset 3.

The primary source of evidence for this study is dataset 1, the 16 interviews. The other datasets contain secondary information, and they serve to record the current opinions of leading actors from industry, politics, and science. Only data published in 2023 has been accepted to secure time coherence within the datasets. Dataset 1 consists of 16 interviews, cited as participant identities (ID) I1 to I16, summing up 702 minutes of recorded audio files. Dataset 2 consists of 17 speeches or panel discussions from conferences, cited as participant IDs C1 to C17, summing up to 425 minutes of audio and video material. Dataset 3 consists of 5 relevant documents, cited as participant IDs D1 to D5, summing up to 116 pages of reports. In total, 38 files have been imported in NVIVO and qualitatively analysed by applying thematic analysis.

The lists of interview participants and the other contributions are attached in Appendix 4 .

Design of the interview outlines

As explicated in Section 4.4.2, the interviews have been intensively and individually prepared to get the most out of the time with the participants. In fact, the interview outlines were a merge of a case study protocol (Yin, 2018) and a semi-structured interview guideline.

Each interview started with individual questions about the information already known from the screening phase. In the case of interviews with project actors, typical questions were:

- Are the project data about budget, timeline, and partners found on the homepage still correct?
- Does the project still belong to the IPCEI project family? Or is there other funding, meanwhile?

- Have there been changes to the project structure or other elements of the project since its launch?

The goal of these questions was twofold: first, the answers helped to verify or falsify the pre-collected information, and these questions served as a warm-up for the more specific questions.

Then, the more specific questions for the project actors asked about the actual project status of potential customers, partners, and suppliers for the project; typical questions were:

- Is the funding approved yet?
- Are there connections to other projects?
- Who are the potential customers? Are there contracts with the customers already in place?
- Who are the potential suppliers? Are there contracts with the suppliers already in place?

Another block of questions asked about the envisaged business activities and the envisaged company structure; typical questions were:

- What business activities does the project plan? How will the money be earned? What is sold?
- Who owns the project and the undertaking? How could it be governed in 2027 or 2030? Are there still investors needed?

The closing questions were about drivers and barriers for the projects and potential future H_2 import into Germany and about the outlook for the year 2030; typical questions were:

- What currently drives the project? What hinders the project?

- Are there any other influencing factors? Are there problems with public acceptance to be expected?
- How do you see the H_2 import topic? Will it be rather a chance or a competition for your project?
- What is your opinion in 2030, will your project have developed a successful business?

This has been a typical outline of an interview with a project manager. Interviews with other stakeholder, such as scientists or politicians have been prepared with adapted interview outlines, some examples are given below.

The interviews commenced by drawing on from the interviewee's previous work, such as a scientist's research report, a politician's statement, or an association chairman's position paper. This initial exploration served as an excellent icebreaker, allowing the interviewees to discuss their contributions comfortably. Subsequently, tailored inquiries were posed, honing in on the individual's expertise and field of knowledge, for example:

- What is the status of the certification for green hydrogen? Where are barriers, and where are drivers?
- At which step of the value chain do you see the greatest need for action?
- Which actors do we see in the hydrogen economy today and tomorrow? Are there new actors coming up? Who? What about the incumbent actors? What roles do they have?
- Which role should the state play? Should there be state-owned hydrogen projects?
- What role do politics, the EU, and national politics have?

- What have to happen that the ramp up of the H_2 economy is quick enough and successful? What are deal breakers, and what are deal makers?
- What does not have to happen, what would be a showstopper for the ramp up of the hydrogen economy?
- How will business models for hydrogen projects look like in Germany in 2030?
- How is the H_2 generation, distribution, and consumption functioning in Germany in future, according to your opinion?
- How should the projects be financed? Where does the money come from to finance the gaps until the offer price for H2 can match the market price?

Although the interviews were conducted individually, some blocks of information were covered in each interview.

These were:

A) Drivers and Barriers

- What drives, what hinders the ramp up of the H_2 economy / the project realisation? Are there any other influences that need to be considered? Deal breakers / Dealmakers?

B) Players in the future "hydrogen business models."

- Who will be the most important players in the future? Are there new players to be expected? Who will play what role? What role will the incumbent companies (energy producers, gas companies) play in future?

C) Funding instruments and IPCEI Process

- Is the IPCEI funding effective? Are you satisfied with the process? What kind of funding is needed?

D) “Hydrogen economy ramp up”

- Will the market ramp-up succeed? What will the hydrogen economy look like then? Who is involved? Is somebody Who earns something from it? When will there be viable business models? What will they look like?

All interviews have been conducted in the German language; the interview outlines were prepared in the German language, and the questions listed above have been translated from German into English.

4.5. The role of theories in this study

Inductive or deductive approach? – Loose or tight design?

As set out in the previous sections of this chapter, this research has been pre-planned to a certain extent; the fine-tuning of the planning has been adapted after the screening phase. The pre-planning encompassed the following major elements:

- the formulation of the aim, objectives and research questions
- preliminary considerations about what information is needed to answer the research questions this led to the information mind maps and the interview outlines and later on to a number of a priori codes for the data analysis
- the development of conceptual models for business model designs (see Section 2.6) synthesised from the literature review and merged with the chosen critical realist perspective

These initial considerations, assumptions, and concepts helped to maintain a focused and efficient approach to data collection and analysis. This approach followed leading scientist in the field of case study research (e.g. Eisenhardt, 1989; Yin, 2013) that highly recommend to have some initial ideas about theories in order to gather “the right" data that is rich enough to provide substantial evidence to confirm, reject or modify the initial theories.

Moreover, the literature review (see Chapter 2) revealed, that there are many concepts available in the field of business model research that can be applied for investigating business models, ignoring this large body of existing knowledge in the field could be deleterious to the quality of the research. However, Diane Vaughan's warning words about tight research designs that can stand in the way of an unbiased approach to the topic have been taken into account:

> "The paradox of theory is that at the same time it tells us where to look, it can keep us from seeing" (Vaughan, 1992, p. 195).

The primary focus of this research was not to validate or invalidate any pre-existing theoretical frameworks. Rather, the objective was to comprehensively understand the real-world dynamics at play in the field. Consequently, while theoretical models provided a valuable starting point for the analysis, they were not rigid constraints but rather flexible frameworks that allowed us to explore and interpret the data with nuance and openness.

Therefore, the research design applied an inductive but framed approach. In the discussion chapter, the initial concepts are replaced by new concepts that better reflect the analysis's results.

4.6. Criticism of research design and established quality criteria

The qualitative research design has been critiqued for issues such as insufficient generalisation, lack of replicability, and transparency (Bryman & Bell, 2015). The study established a rigorous research design to address these concerns and ensure academic quality. The quality of the research was maintained throughout different phases by adhering to specific criteria and concepts.

Following the critical realist paradigm of this research, the concepts of “reliability”, “validity” and “reflexivity” (e.g. Bryman & Bell, 2015; Easterby-Smith et al., 2018; Miles et al., 2014). have been selected for describing the quality of this research. The specific understanding of those terms and the exertion of the related concepts are outlined in the following.

In this research, "reliability" is synonymous with "auditability," ensuring that processes and activities are well-documented and can be repeated with the same results. Measures for reliability were established through systematic documentation of procedures, maintaining a case study database, and using software for managing and analysing data, e.g.:

- designing the literature review as a systematic literature review, documenting search terms, hits and criteria for selecting the relevant literature
- developing and maintaining an Excel sheet's case study database (the “IPCEI project list”). Preparing individual case study protocols for the interviews and audio recording during the interviews to keep a traceable line of inquiry and line of documentation for the results during the data collection and analysis phase
- using software (Unipark, NVivo) for managing, processing and analysing the data. Those software packages ensure the data is securely stored and cannot be manipulated. Keeping the chain of evidence (Yin, 2018) and reliable audit trails is supported by those software packages
    - the literature has been analysed in NVIVO (nvivo.de)

  - the survey has been designed, conducted and evaluated by using Unipark (unipark.com)
  - the coding, the thematic analysis of the interviews and other data sets has been done in NVIVO (nvivo.de)

"Validity" is split into "external validity" and "internal validity" in this research. "External validity" addresses the transferability of the findings to other cases and the generalizability of the results. It has to be acknowledged that generalizability in qualitative case study research might be intrinsically limited because case studies refer to real-world situations in the specific contexts (Miles et al., 2014; Yin, 2018), which might not be easily transferable to other cases. Nevertheless, effort has been made in the research design and the sampling process of the cases to build in external validity, e.g.:

- designing this research using a broad database, i.e., talking to several project managers of different IPCEI projects and conducting a survey
- gather a holistic view of the research topic, i.e., interview other experts, such as researchers, consultants, and politicians. Integrate conference contributions, panel discussions, and speeches from opinion leaders in the H_2 economy
- use the IPCEI projects as a basic frame from which to sample the cases. As all IPCEI projects had to pass the same framework and criteria given by the public funding scheme, the similarity and, therefore, basic comparability of the cases are given
- rely on the same theory and models for analysing all data sets, i.e. using the same coding scheme for data analysis, should minimise bias and subjectivity in the data analysis process

“Internal validity” is a controversial term in qualitative research. While some authors link internal validity to credibility and authenticity (e.g. Guba & Lincoln, 1994; Miles et al., 2014), others understand internal validity as generally the degree of academic rigour applied in the research (Easterby-Smith et al., 2018). The latter view is adopted for this thesis. Hence, internal validity encompasses triangulation, the thoroughness of the analysis, the investigation of rival explanations, etc. Several elements of internal validity have been established in this research, e.g.:

- collecting evidence from multiple sources (documents, websites, press releases, governmental documents survey, interviews, observation and talks during conferences)
- comparing and contrasting the findings with theories and prior logic models (e.g. the conceptual frameworks from literature review)
- allowing flexibility in semi-structured interviews if there is something unexpected occurring with the goal also to explore what is out there and not only what has been expected to be out there

"Reflexivity" involves reflecting on the researcher's influence on the research process and results (Gray, 2013; Guba & Lincoln, 1994). This includes self-reflexivity about whether prior instrumentation about data collection and analysis has worked. Reflexive practices have been established in different phases of the research, including making explicit the philosophical fundament this research is grounded on, including the researcher’s values and beliefs (Chapter 3), reflecting and adapting research questions based on findings during the screening phase (Chapter 5), reflecting after each interview to improve future interviews, and critically assessing results related to the aim of the research in the conclusions section (Chapter 8).

In essence, this study has effectively countered criticisms aimed at qualitative research design. It achieved this by implementing robust measures for reliability, broadening external validity through diverse sampling techniques, upholding internal validity via rigorous analysis methods, and integrating reflexive practices to bolster research quality. These concerted efforts have steadfastly upheld academic rigour across all stages of the study.

4.7. Research Ethics

Today many codes exist on how to conduct research ethically. For example, universities, government institutions (e.g. Commission, 2013; UoG, 2021), but also associations, such as the American Psychologist Association (APA), have developed standards and guidelines for research and also have established ethics committees that review research proposals regarding their ethical integrity.

Today, broadly speaking, research ethics covers two areas, which are

- research integrity and
- questions of human rights (Commission, 2013).

Research integrity emphasises conducting research with excellence and quality, free from scientific misconduct and external influences (Commission, 2013). The research excellence and the quality criteria of this research have been unfolded in the previous section (Section 4.6).

The second area of concern, the treatment of human rights in research, and its application in this research are unfolded in the following.

The Nuremberg Code (Shuster, 1997), crafted in the aftermath of World War II, established ethical guidelines for medical research involving human subjects, emphasising principles such as beneficence, non-maleficence, and respect for participants' rights. Today, ethical standards from the Nuremberg Code govern research across various disciplines. While particularly relevant in fields such as medicine, psychology, and social research, ethical considerations are also essential in all other research disciplines, including business research. This encompasses protecting participants' anonymity and confidentiality, obtaining informed consent, and safeguarding the interests of researched organisations.

According to the European Commission, “Ethics is an integral part of research from beginning to end, and ethical compliance is pivotal to achieve real research excellence” (Commission, 2013, p. 2).

The University of Gloucestershire's formal ethical review process has ethically reviewed the study's research design. An ethical concept has been framed based on the university's ethics policies (UoG, 2021) and the framework of the EU, displayed in the publication “Ethics for researchers” (Commission, 2013).

The qualitative case study design integrates a comprehensive array of research methodologies, including secondary desk research, insights from social media platforms, and direct engagement via primary research tools such as questionnaires and interviews. While the inherent nature of the research context and topic may not inherently present significant ethical dilemmas, it remains paramount to adhere to established principles safeguarding participant welfare and upholding research integrity. To this end, an in-depth examination of potential ethical concerns and the strategies employed to address them is outlined in Table 6, underscoring the attention paid to ethical considerations throughout the research process.

Table 6 Ethical concept applied for this study

Potential ethical issue	How the issue is addressed, handled, mitigated
1) Beneficence	The research has value for academia, politics and economy, see Contributions Section 8.3
2) Autonomy and respect	Participants are volunteers and can withdraw any time from participation, they are fully informed about content, also participants have the opportunity to review their statements, see information and invitation letters for questionnaire and interviews in Appendix 2
3) Non – maleficence, in this case privacy, confidentiality	The research does no harm. Protection of informants, cases, organisations are ensured by anonymization of interviewees' names and anonymized and disguised information for projects/cases. See Appendix 4 for overview on interviewees and conference contributions.
4) Fidelity, integrity, honesty	Scientific misconduct is excluded by researcher's personal ethical principles (see thesis declaration) and by including quality criteria in design and conduct (see 4.6)

Overall, the study demonstrates a commitment to ethical standards by addressing potential ethical issues and establishing measures to protect participants' rights and maintain research integrity. These efforts align with broader ethical considerations in academic research.

4.8. Concluding the chapter: Summarising the research design and transitioning to Part 2

This chapter has presented and justified the research design for this study. The research is designed as a case study, being conducted in two phases, a screening phase first, followed by the main phase. The study design employed a mixed method approach with a small amount of quantitative data collected in form of a survey and a large amount of qualitative data collected in form of telephone contacts, interviews, conference contributions and desk research. All field data were collected between February 2023 and August 2023.

Rigour and the broad use of software helped to organise the data processing and helped to manage large amounts of data. An online software tool (Unipark) was used for conducting the survey and creating automated reports. The interviews and conference contributions were recorded, transcribed, and then analysed in NVIVO by thematic analysis. All other data collected during desk research or notes during phone calls and conference talks were collected in a large spreadsheet in Excel. The findings and results of the study are presented in narratives, tables and graphic illustrations in Part 2 of this study.

The extensive utilisation of software bolstered reliability and auditability and incorporated additional measures within the design to enhance quality. For instance, employing a diverse array of evidence sources and selecting interviewees with varied profiles significantly bolstered the validity of the process.

The research concept has passed the formal ethical review process of the University of Gloucestershire. Furthermore, an ethical concept was applied to the study to ensure anonymity, autonomy, and respect for the participants.

Transitioning to Part 2

Part 1 has instituted the topic of this thesis and its context, “Emerging business model designs for the hydrogen economy: An explorative enquiry into the German IPCEI projects”. Chapter 1 presents the context of the research, its relevance and its topicality, which refers to the broad field of energy transition and climate goals of the EU. In the course of 2022, the topic of green hydrogen production via electrolysis has gained even more importance as it provides the potential to raise energy independence from fossil energy carriers, such as natural gas. Independence from energy imports has become more important since Russia has limited gas supply to Europe in 2022.

Chapter 2 presents the outcomes of a systematic literature review on the study's focal point. This comprehensive review uncovered a wealth of academic insights about business model research. However, the exploration also unveiled a notable scarcity in the literature concerning business models specifically tailored for green H_2 generation projects. In fact, no existing sources were found that delve into the intricacies of business models tailored to this domain. To address this gap, the activity system-based view on business models as proposed by Zott and Amit (2010) has been embraced and further expanded upon by Casadesus-Masanell and Ricart (2010). These frameworks serve as the initial conceptual foundation for investigating business model designs pertinent to the study.

In Chapter 3, the research is nested in the philosophical background of the researcher and the paradigm of critical realism enriched with elements of systems thinking philosophy is selected and justified as underlying research tradition.

Chapter 4 presents the detailed design of the study, discussing and justifying methods and methodological choices. The research is designed as a qualitative multiple-case study. Evidence is to be collected mainly from documents and interviews. The analysis design follows mainly an abductive “comparing to theory approach”; some analyses follow an inductive approach. The overall design relies on prior instrumentation but allows flexibility if unexpected themes emerge during research, as analysis and data collection are performed in parallel. An ethical framework and quality criteria are established to ensure rigour and “good research”.

In summary, Part 1 presents the research theory, establishing the frameworks and underlying theories. The research has been prior instrumented and structured to a considerable degree to enhance efficiency during the practicable phases of the work, data collection, and analysis, which are presented in Part 2.

Part 2 encompasses the empirical case study, incorporating comprehensive data collection, diverse analysis, and reflective evaluations. It delves into the efficacy of prior instrumentation, the adherence to research design, and the necessity for adjustments where inadequacies were discovered. Within this section, the results and findings are evaluated, culminating in proposing a conceptual business meta-model framework for the H_2 economy. In its concluding chapter, Part 2 synthesises the study's insights and articulates its contributions to both theoretical understanding and practical application.

Part 2 Data collection, analysis and conclusion

5. Phase 1 “screening phase” finding and results

5.1. Introduction into the chapter

As set out in Chapter 4 the purpose of the screening phase was to get an overview over the status of the IPCEI projects in Germany at the beginning of the fieldwork for this study. Furthermore to learn what happened since the announcement of the projects in May 2021 (BMWI, 2021a) and to find out what information about the projects’ business models is available and accessible at this point in time. The information gathered and analysed was used to refine the research question and to further frame the main phase of the research.

The data collection for the screening phase took place between December 2022 and March 2023; three major activities have been performed:

1. Desk research: Collecting basic up-to-date data about the 62 IPCEI projects, for results see 5.2.
2. Phone contact: Contacting the projects by telephone to verify or falsify the information gathered by desk research, to identify suitable candidates for the in-depth interviews and to obtain their consent to participate in the survey, for results see 5.3.
3. Survey: A questionnaire was designed and sent to the persons who had given their consent. Some of the questionnaires were also forwarded to other stakeholders of the IPCEI process, such as associations, which act as multipliers for expressing the opinions of the project stakeholders, investors, and politicians. The results are described in Section 5.4.

5.2. Outlining the starting point of the fieldwork: The status of the German IPCEI H_2 projects in December 2022

The German Federal Ministry for Economic Affairs and Climate Action provides information about the IPCEI hydrogen projects on its website (BMWK, 2023e) and offers links to updated information. The market ramp-up of hydrogen technologies is being supported through the funding instrument of the IPCEI program, which stands for "Important Projects of Common European Interest." This funding supports investment projects of collaborating European companies to enhance growth, employment, innovation, and global competitiveness across Europe. The instrument is designed to promote integrated projects along the entire hydrogen value chain, including producing green hydrogen, hydrogen infrastructure, and using hydrogen in various industries and applications. The German IPCEI H_2 projects are set to receive over eight billion euros in federal and state funds. These state aids are expected to stimulate additional investments of 33 billion euros by industrial companies in Germany for these projects (BMWK, 2023e).

The H_2 IPCEI campaign in Europe started end of 2020 (BMWK, 2023e). Until February 14, 2021, in Germany, over 230 project sketches were submitted by single companies or project consortia, expressing their interest to launch an IPCEI H_2 project (BMWI, 2021b). In May 2021, the BMWK (2023e) selected 62 projects from the 230 proposed and declared them generally eligible for IPCEI funding. The selected projects represented the entire value chain of the hydrogen market, i.e. H_2 generation, H_2 infrastructure, H_2 use in industries and H_2 use in mobility. The IPCEI location map, (see Figure 19) was published by the BMWI (2021a, 2021b) in May 2021 and shows those 62 projects and their spread across Germany. The 62 projects are grouped into four categories. Nineteen projects are categorised as “H_2 generation”. They include projects for the fabrication of key components, such as electrolysers (e.g. MAPEVA, H_2-SARA) and fuel cells (e.g. Bosch Power units), and they include projects which build large-scale electrolysers (e.g. HGHH, doing hydrogen). The colour coding and numbering of the entry in the location map in Figure 19 indicates which IPCEI project it is. The list on the right side of the graphic (Figure 19) gives the name of the IPCEI project and the name of the company mainly involved. The information in this graphic and several press releases of the ministries administrating the IPCEI projects (e.g.BMWI, 2021a, 2021b; BMWK, 2023e) was the starting point for the desk research, which is presented in the next section.

Figure 19 The 62 pre-selected German IPCEI H_2 projects as of May 2021 (BMWI, 2021b)

5.3. Desk research and phone research proceeding and results

5.3.1. Proceeding the desk research and the phone calls

During the desk research, the internet was searched with various search terms and combinations of search terms, such as the “project name”, the “company names”, the term “IPCEI”, and so on. By doing so, general information about the projects was collected, such as websites, contact persons, project scope and budget, etc. A special focus was put on up-to-date information about the projects and the context of the projects, which was done by limiting the search to hits from the past 12 months. The scope of the search encompassed all 62 IPCEI projects as announced by the BMWI (2021b) and shown in Figure 19.

During this desk research, publicly available basic information related to most projects could be found and compiled in an Excel spreadsheet. Figure 20 shows a screenshot from that Excel list.

	Project name	Webseite	Which products & services?	Partners (how many?, Who?)	Project budget
H2-Generation					
1	AquaVentus (RWE Renewables)	https://aquaventus.org/	H2 Erzeugung aus Offshore Wind (10GW); H2 offshore Pipeline + Hafeninfrastruktur,	ca 100 Partner (Website Förderverein)	
2	HGHH	https://www.hghh.eu/ (= Hamburger Green Hydrogen Hub)	H2 für Industrie, H2 Pipeline, H2 für Mobilität, Wind- und Sonnenkraft	4 Partner (Shell, MHI, Hamburger Energiewerke, Vattenfall)	ca 660Mio€
3	Clean Hydrogen Coastline (EWE/EWE Netz/swb)	https://www.swb.de/ueber-swb/unternehmen/nachhaltigkeit/wasserstoff/clean-hydrogen-coastline https://www.ewe.com/de/media-center/pressemitteilungen/2022/10/ewe-plant-wasserstofferzeugung-im-kraftwerksmastab-in-ostfriesland-ewe-ag	H2 mit insgesamt ca 400MW für Mobilität und Industrie, zB steel production in Bremen	6 Partner; ArcelorMittal, EWE, Tennet, Gasunie, swb	500Mio € für die 320MW Anlage, 1,3bill€ fürs Gesamtprojekt
4	Get H2	GET H2 allgemein: https://www.get-h2.de/ https://www.rwe.com/der-konzern/organisationsstruktur/rwe-generation	H2 für Raffinerie, Chemieparks, Stahlwerke, H2 Transport/Logistik und Cavernenspeicher	RWE, BASF, BP, Evonik, Nowega, OGE, Thyssengas ...in Summe 13 Förderpartner	2,3 Mrd€ in Summe für Get H2

Figure 20 Clipboard screenshot from “IPCEI project list” (author’s own)

The file “IPCEI project list” was the central database for the screening phase.

The basic information about the projects covers project names, websites, and contact persons. Furthermore, information about the envisaged project budget, project partners, and the planned commissioning date is publicly available and included in the database for most of the projects.

Although the information was publicly available, it quickly became clear that its factual content was questionable. Some published information was ambiguous, outdated, and, in some cases, even contradictory. So, it was decided to contact the projects directly by phone to obtain direct information and collect a more valid picture of the situation.

This activity turned out to be very rewarding. Already after the first phone calls it was decided to complement the primary data collection by conducting a survey to gather the views of as many project stakeholders as possible (see 5.4). The notes taken during the phone calls were also documented in the Excel database “IPCEI project list.”

5.3.2. Results of desk research and phone calls

The "IPCEI project list" analysis aimed to identify accessible projects and determine which business model-related aspects are most compelling for further investigation during the main phase of the research.

Expanding upon the theories and concepts elucidated in Part 1 of this thesis (Chapter 2.6, Figures 8, 9, and 10) concerning the analysis of business model designs, the projects are examined by scrutinising the content and structure of their businesses.

Applying this view to the 62 IPCEI projects, they can be grouped based on their similarity in covering the value chain of the H_2 economy. This analysis leads to the clustering of six groups, explained below and illustrated in Figure 21:

Group 1 “one product” IPCEIs:

These IPCEIs produce one product, component, and technology, e.g. fuel cells, electrolysers, vehicles, etc. These projects are usually only developed by one company or by a spin-off of one company. Following the project numbers of Figure 19, examples for this type are #6 “MAPEVA” and #10 “H_2-SARA”, both producing electrolysers. Several projects are developing fuel cells, e.g. #19 “Bosch Power Units”, #52 “BMW product”, and #53 “Brennstoffzellen Gigafactory”. Some projects developing H_2 powered vehicles, e.g. #54 “PEGASUS” (trucks), #58 “WIPLIN” (airplanes), still others develop technologies, e.g. for the use of H_2 for direct reduction processes in steel production, these are the projects #38 “DRIBE, #43 “tkH_2steel”, #48 “H_2 Syngas”.

Group 2 “complete value chain” IPCEIs:

IPCEIs that cover the complete value chain within one IPCEI project. The value chain spans from electricity generation to H_2 production to H_2 transport and H_2 use. Following the project numbers of Figure 19, examples of this type are #49 “BayH_2”, #50 “RHYME Bavaria”, and #35 “HySCALE 100”. Those projects are usually developed jointly by several companies, each covering an element of the value chain.

Group 3 “part value chain” IPCEIs:

This group is rather small; only two of the projects, #17 “GH@BD” (Green hydrogen at Blue Danube) and #18 “HyTechHafen,” were assigned to this group. According to current knowledge, both projects seem to cover hydrogen production and hydrogen logistics but do not incorporate hydrogen use; in other words, they do not have any off-takers for H_2 within their project consortia.

<u>Group 4 “joint project” IPCEIs:</u>

This group contains IPCEIs that cover one step of the value chain in one project but have joined up with IPCEIs of complementary activities. Following the project numbers of Figure 19, examples of this type can be recognised by an overall name for the project, e.g. “AquaVentus”, “Clean Hydrogen Coastline”, “Get H_2”, “doing hydrogen”, “GreenOctopus”, “LGH$_2$” and the projects around the Hamburg harbour. The activities of the diverse sub-projects are complementary. For example, the “Get H_2” project encompasses sub-projects dealing with H_2 production, with H_2 transport via pipelines and H_2 storage in caverns, and the usage of H_2 in steel fabrication.

There are seven of those joint IPCEI initiatives amongst the list of 62 IPCEI projects. A total of 33 of the 62 projects belong to one of these seven joint projects; it is therefore by far the largest group.

As far as observed during the screening phase, those projects have a similar appearance and structure. They usually entertain a common webpage with basic information about the various sub-projects, such as partners, basic activities and news about the project. They are often accompanied and supported by some kind of umbrella organisation or association, which takes over marketing and communication activities or other coordinative tasks; the Hy-5 initiative (www.hy-5.org) is an example of such initiative.

The screening phase did not delve deeply into investigating the dynamics within these joint IPCEIs, so determining whether these coalitions already operate as business ecosystems (as indicated in Table 2 of Chapter 2.5) or if they maintain looser connections remains inconclusive. Nonetheless, the potential emergence of business ecosystems aligns with the findings from the literature review (Chapter 2.5). This particular aspect received further scrutiny in phase 2, as outlined in research question 3 (RQ 3).

Group 5 “dedicated purpose” IPCEIs:

From the point of view of the business model design, another group was formed to which the IPCEI projects were assigned, which particularly fulfilled a dedicated purpose of general interest. Examples of such projects are #51, “SENECA”, which aims to expand the hydrogen refuelling station network and build truck refuelling stations and #24, “HyPerLink,” which plans to build H_2 pipelines connecting Danmark and the Netherlands to Germany, fulfilling the European government mandate to build the so-called European Backbone H_2 grid (EHB, 2022).

Group 6 “no information” IPCEIs:

For the sake of completeness, to be able to assign all 62 projects to a group, Group 6 was created. Group 6 contains the remaining four projects, where no information could be found during desk research, as already mentioned above, e.g. projects #13, #16, #44, and #45.

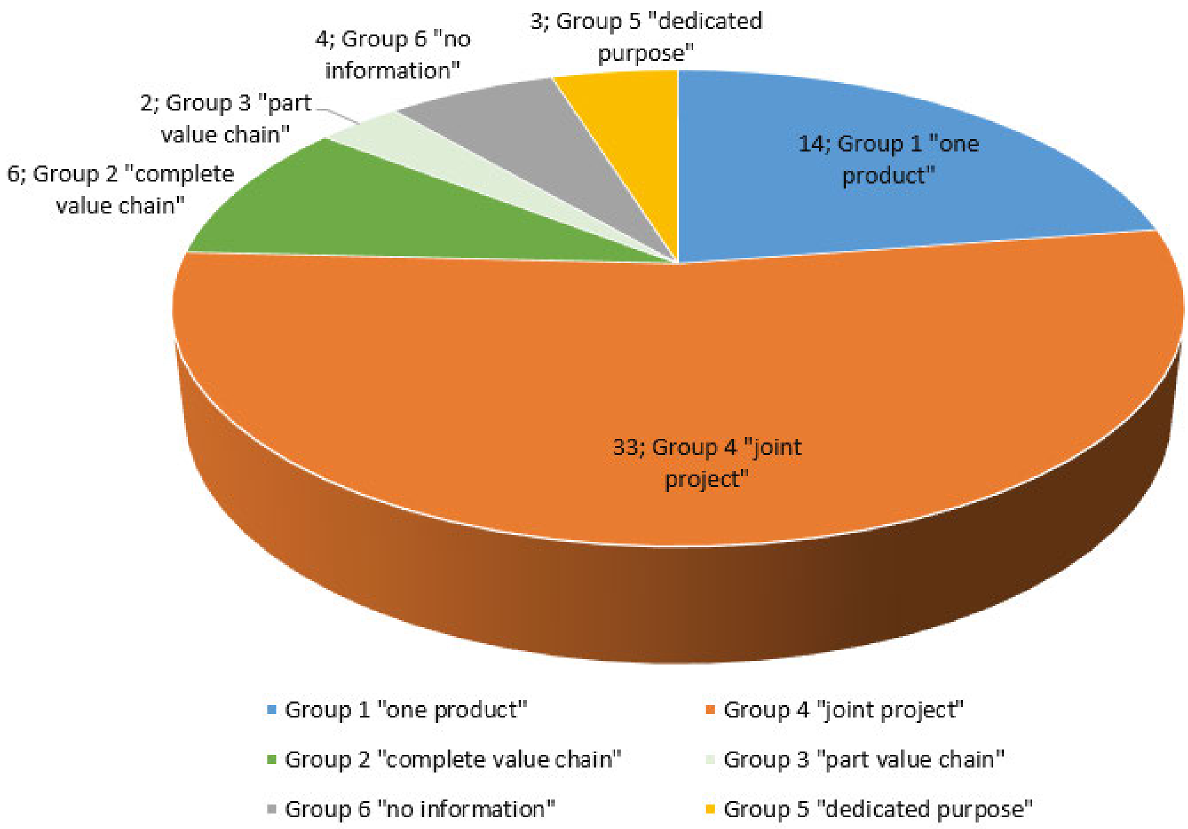

Figure 21 IPCEI project clustering by business model “value chain coverage” (author’s own)

As this thesis investigates business model designs for the H_2 economy and not only for one product or company, Group 2, Group 3 and Group 4 projects are interesting for further investigation in the main phase.

The telephone calls with project actors revealed further interesting information about the current situation of the 62 IPCEI projects and how the project actors perceive the course of action.

In summarising the developments since the presentation of the 62 projects in May 2021, it is clear that many changes have occurred, rendering the original list obsolete for updating. These changes have originated from both the EU and the projects themselves. Delving into each alteration would exceed the intended scope and focus of this thesis. However, it is important to note that during telephone discussions, many project stakeholders voiced concerns regarding the adverse effects these changes have had on their respective projects. The primary ramifications, as highlighted in these conversations, are outlined below:

In the summer of 2022, the EU announced the bundling of the IPCEI project proposals in four waves and proceeded with the notification of the projects sequentially according to these four waves: 1. Technology (Hy2Tech), 2. Industry (Hy2Use), 3. Infrastructure (Hy2Infra) and 4. Mobility & Transport (Hy2Move). The notification by the EU is the prerequisite for the projects to receive national funding that is above the otherwise specified level in the EU. An attractive funding quota that helps to finance the investment is essential to achieve economic viability for the projects (BMWK, 2022).

This sequential process has led to significant delays in the notifications and significantly delayed project executions. Although some of the telephone partners expressed understanding for the EU officers, who were overwhelmed by a large number of IPCEI proposals that now have to be evaluated, they see the delay of the projects as very critical, especially in relation to the global competition in the field of hydrogen technology. “Time matters for Germany”, as one of the telephone partners said (phone partner 1). This comment was also meant in relation to increasing project costs due to inflation and energy shortages.

The telephone partners highlighted additional administrative burdens imposed by the EU, including the necessity to compile an extensive "umbrella agreement" spanning up to 500 pages for each wave. Subsequently, every project undergoes a meticulous two-stage application process, with stakeholders anticipating multiple rounds of inquiries from the EU. Furthermore, adjustments have been made to the selection criteria for project eligibility. Some partners emphasised the shift in focus regarding project eligibility criteria. While previously emphasising the completeness of the value chain, diversity of applications for hydrogen use, and pan-European collaboration with IPCEI projects in other countries, the emphasis has now shifted towards the degree of innovation and aspects of differentiation. Consequently, numerous hydrogen mobility projects have been deemed insufficiently innovative and are consequently now ineligible for funding.

The project stakeholders perceived the EU's and the national level's actions as “very unfortunate, as the rules of the game were changed during the ongoing proceedings, which has caused great frustration among the actors” (phone partner 2) or, in shorter words, during another call, “we are really upset” (phone partner 3).

How does this affect the 62 German IPCEI projects?

For the German IPCEI projects, these rule changes have resulted in several turbulences and delays: About a handful of mobility projects dropped out of the IPCEI projects (e.g. project #51, #59 to #62 of the “IPCEI project list”) and are now either abandoned or try to acquire other funding sources. Some projects of the later waves merged or developed a different industrial scheme and reached out for different funding sources to avoid too long delays for their implementation (e.g. #17, #37, #38 of the “IPCEI project list”). In July 2023, the EU announced the approval of the first projects of the Hy2Tech wave and the Hy2Use wave (BMWK, 2023e; Spiegel, 2023). Out of the 62 German projects, #10, #15, # 19, #21, #41, 43, #53, #54, and #55 of the “IPCEI project list” have received approval and can now launch preliminary kick-off, however for some of those projects the mandatory national (German) funding has not yet been secured.

And how have these insights affected the further research for this thesis?

Through the desk research and even more so through the phone calls, it became very clear that this study's research field is characterised to a high degree by volatility, uncertainty and agility; it is settled in a VUCA (volatility, uncertainty, complexity, ambiguity) environment. It was not expected that the projects would constantly be subject to changes in many dimensions, such as their scope, industrial scheme, timeline, and so on. The related business models also appear to be subject to numerous changes; today, they seem far less defined than initially thought. Furthermore, it became clear that through merges and the building of large “joint projects” that consist of several sub-projects (see Group 4 “joint projects” in Figure 21) which name the same contact person for the information (see Figure 20 screenshot) the number of projects interesting and accessible for in-depth interview is far smaller than the original envisaged 62 projects.

To avoid having to rely the analysis for this thesis on a too-small database of only a few in-depth interviews, the decision has been made to send out an anonymous questionnaire to the project actors and also to organisations that represent the interests of the project stakeholders, their contacts have also been noted in the Excel spreadsheet “IPCEI project list”. The questionnaire collected the project stakeholders' opinions about the IPCEI projects' current situation, such as the IPCEI process, funding instruments, obstacles and drivers for the project, etc. The survey ensured data collection from a broader basis; the content and results are presented in the next chapter.

5.4. Survey proceeding and results

The unexpected information about the situation and changes that happened to the IPCEI projects since their launch in May 2021 motivated the design of a questionnaire (see Section 4.4.3 for questionnaire design) to broaden the primary database for the study and to collect more primary data from a larger number of stakeholders of the IPCEI projects.

The questionnaire is vital in enhancing the understanding of the IPCEI hydrogen projects. Its primary aim is to gain valuable insights into the field's current state and prevailing sentiments. Furthermore, it seeks to ascertain stakeholders' perspectives on the influence of various contextual factors, including EU decarbonisation objectives, funding initiatives, and regulatory guidelines. Through this inquiry, a comprehensive understanding of the landscape should be achieved, enabling to make informed decisions moving forward in this research.

The survey has been announced in the phone calls (Section 5.3.2) and a link to the anonymous web-based questionnaire has been sent directly after the call. The next section presents the selected results of the questionnaire; the complete results, including the questionnaire, are attached in Appendix 3

The following graphics are selected evaluations of the questionnaire contributing to the previously described focus of interest. However, the automatically generated full report using the reporting tool of the web-based software EFS reporting+ (unipark.com) contains the evaluation of all questions and is attached in Appendix 3

Introduction to the survey

The survey concerns the status and progress of the IPCEI projects and aims to learn about the participants' concerns, motivations, and sentiments. It was conducted during the screening phase of the study, roughly between February 2023 and May 2023. The information was collected through an anonymous web-based questionnaire using Unipark online survey software (unipark.com).

The survey has five parts. The first part (A) is about the products and services in the IPCEI project. The second part (B) is about the project's progress. The third part (C) is about the perceived drivers and barriers in the projects. The fourth part (D) is about the IPCEI projects in the context of the current politics. The fifth part (E) concludes the survey with some statistical information. Up to 30 respondents answered the questionnaire. However, it was allowed to skip questions, which is why the participation rate for the individual questions varies between N=24 and N=30. The respondents are actors and stakeholders of the German IPCEI projects. They have been recruited from the Excel spreadsheet "IPCEI project list" (Figure 20).

In the following parts, major findings from this survey are presented and analysed; the full report is available in Appendix 3 .

Main body of the survey

A) Your IPCEI project: products & services

The initial segment of the survey provides insights into the products and services slated for inclusion within the associated IPCEI project. A significant proportion of respondents are actively involved in projects focused on hydrogen production, comprising 48% of the total (refer to Figure 22). Moreover, key services anticipated within these projects include hydrogen distribution (41%), as well as its application for mobility (37%) and industrial purposes (33%) (see Figure 23).

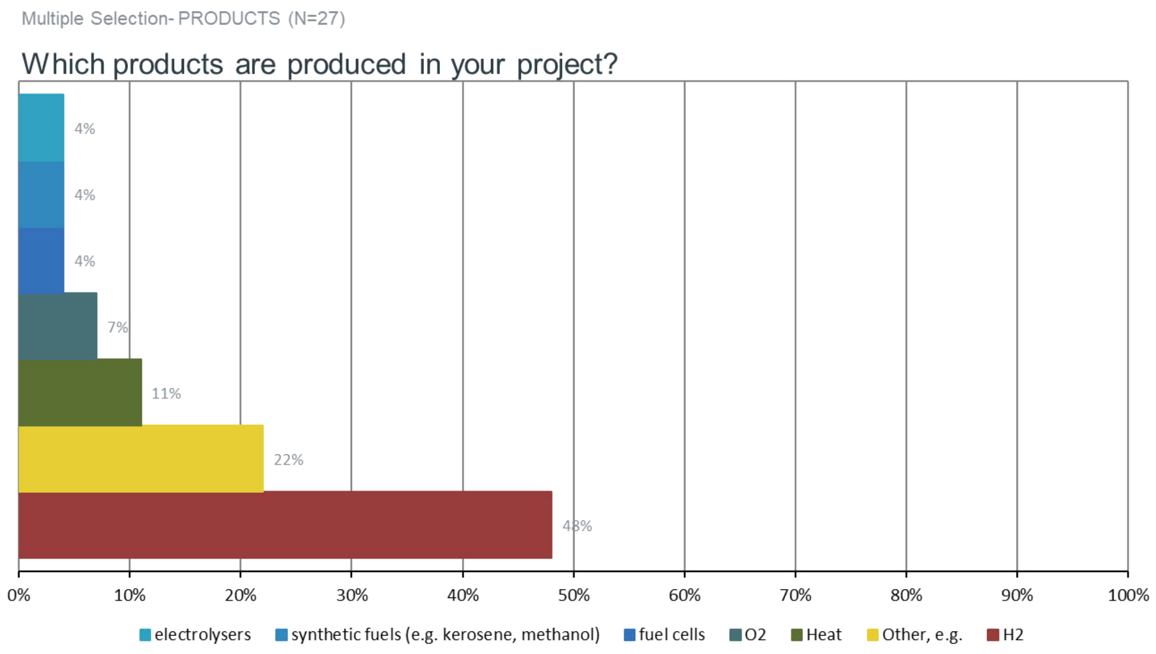

Figure 22 Survey results: Products (author's survey)

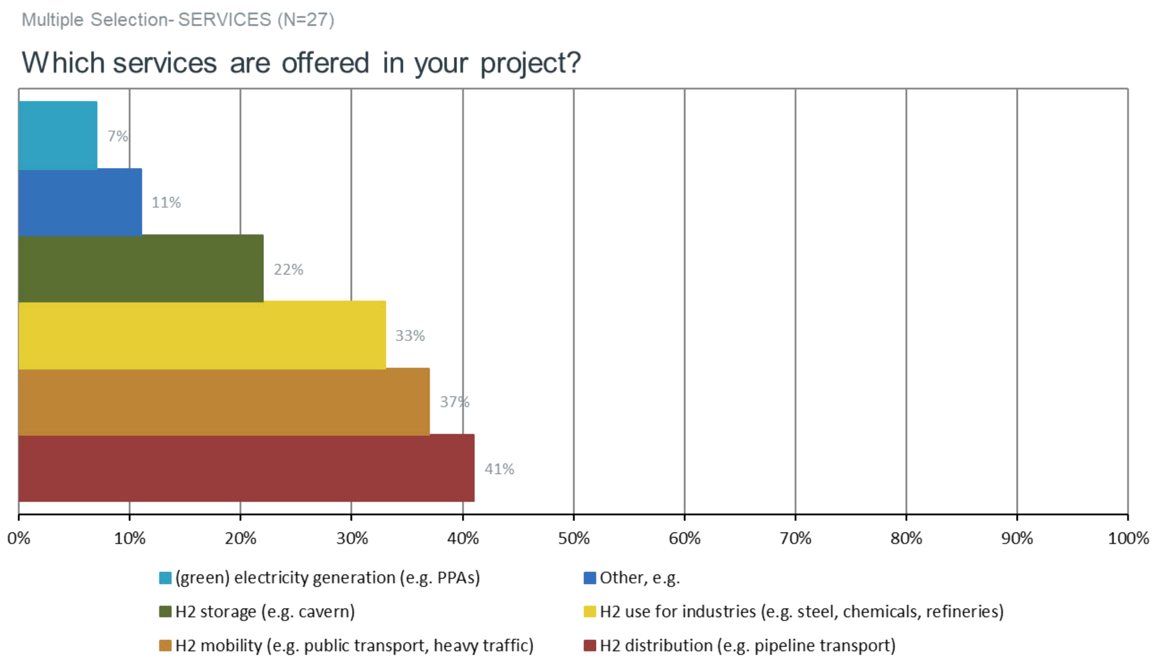

Figure 23 Survey results: Services (author's survey)

Therefore, it is concluded that H_2 generation, H_2 distribution, H_2 for mobility and H_2 for industrial use are currently the most important applications for the H_2 economy.

B) Your IPCEI project: project progress

The second part of the survey informs about the actors' satisfaction with the project progress and the status of the project progress. The participants were not satisfied with the progress, over 90% are either "absolutely dissatisfied" or "dissatisfied" with the progress, see Figure 24.

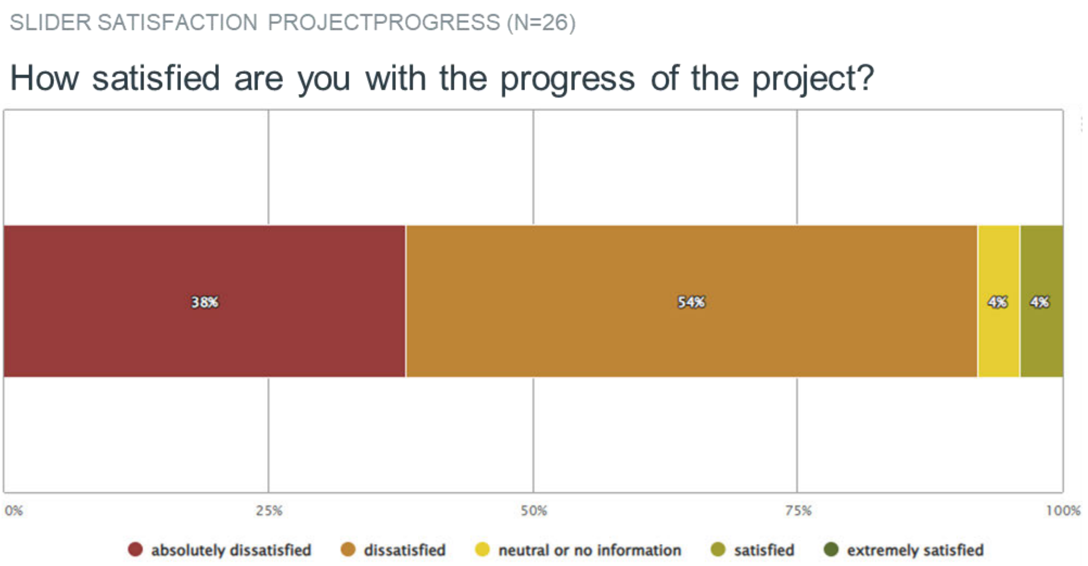

Figure 24 Survey results: Project progress (author's survey)

The projects' progress status averaged 22.8% on a scale ranging from 0% (indicating the status of the projects at their selection (May 2021) to 50% (indicating the completion of the FID (final investment decision) to 100% (indicating the commercial operation of the project), see Appendix 3.

Numerous participants utilised the text field in the survey to provide further insights and express their concerns. They emphasised the necessity for "significantly less complexity" and highlighted how challenging framework conditions have hindered their ability to make decisive moves. For detailed survey findings, please refer to Appendix 3.

Therefore, it is concluded that the progress of the IPCEI projects is far behind schedule, and the actors are highly dissatisfied with the sluggish processes.

C) Your IPCEI project: drivers & barriers

The third part of the survey discusses the drivers and barriers to the projects' business models as perceived by the respondents. The participants ranked an increasing market demand for H_2, a clear regulatory framework and the availability of the funding grant as the most relevant drivers for the project's business model (Figure 25).

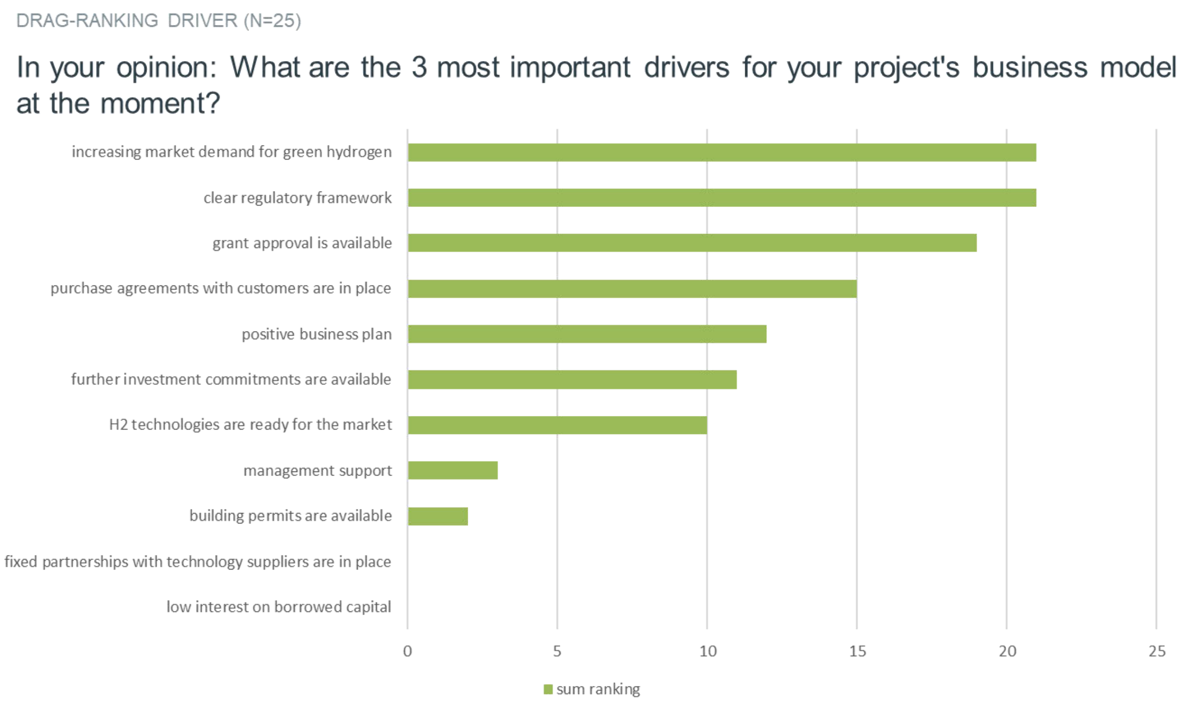

Figure 25 Survey results: Most important project drivers (author's survey)

The biggest barriers were also ranked. These were an unclear, respectively, adverse regulatory framework and pending funding commitments (Figure 26).

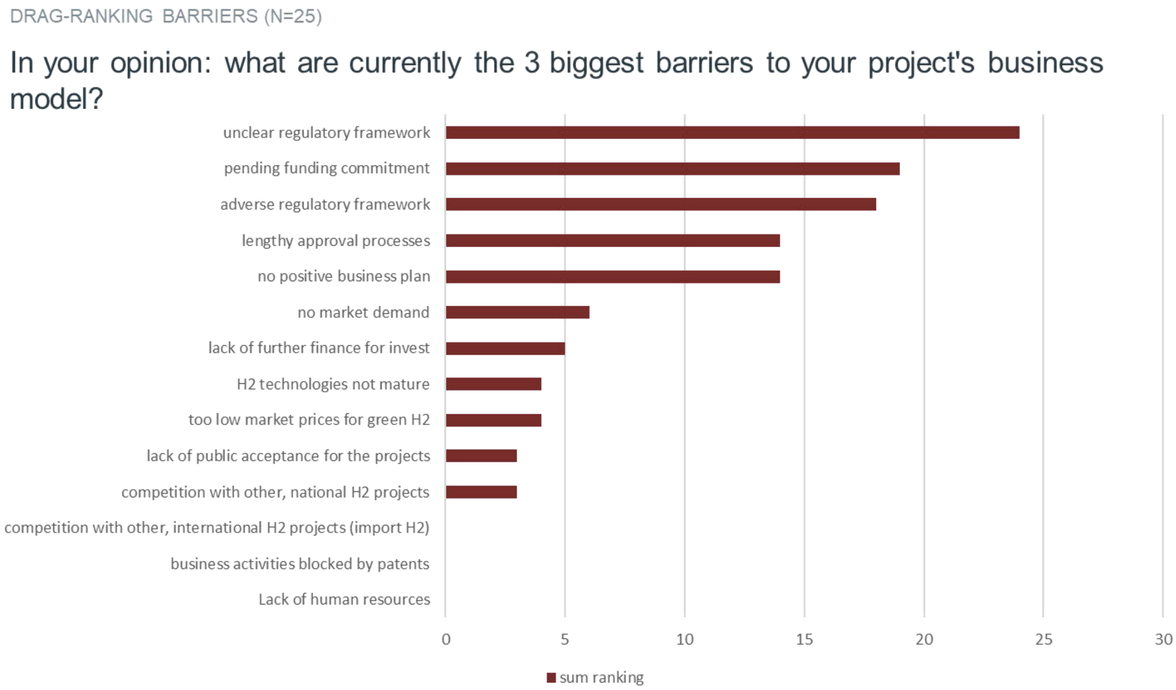

Figure 26 Survey results: Biggest project barriers (author's survey)

Therefore, it is concluded that the availability of sufficient funding, the establishment of a favourable regulatory framework and the existence of a relevant market demand for green H_2 are the most relevant factors for those project actors who answered the questionnaire.

D) The H_2 IPCEI projects in the context of current politics

The fourth section of the survey delves into the contextual factors and external initiatives influencing the progression of the hydrogen economy. Respondents are asked to evaluate various factors impacting this trajectory. Notably, respondents rank the EU climate goals and national H_2 roadmaps as paramount contextual topics, as illustrated in Figure 27.

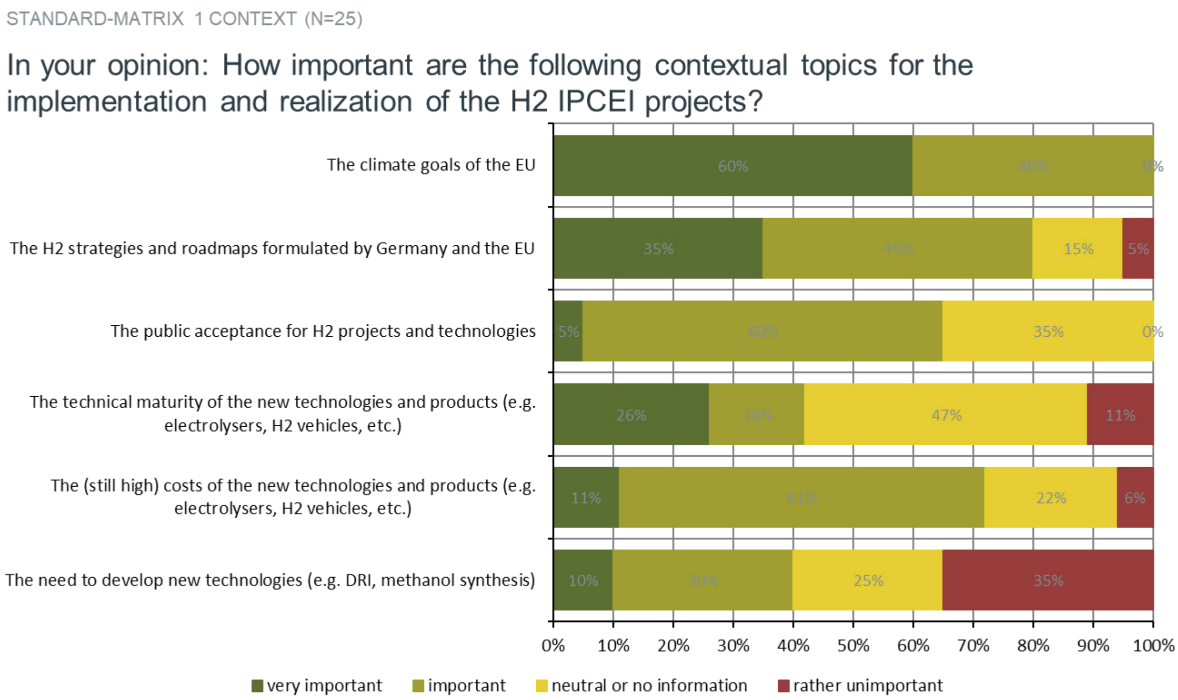

Figure 27 Survey results: Importance of contextual topics (author's survey)

Furthermore, respondents recognise the significance of other initiatives, such as funding programs for capital expenditure (CAPEX) and operating expenditure (OPEX), the implementation of CO_2 pricing mechanisms, and the streamlining and standardisation of regulatory requirements. These aspects are deemed important or very important, as depicted in Figure 28.

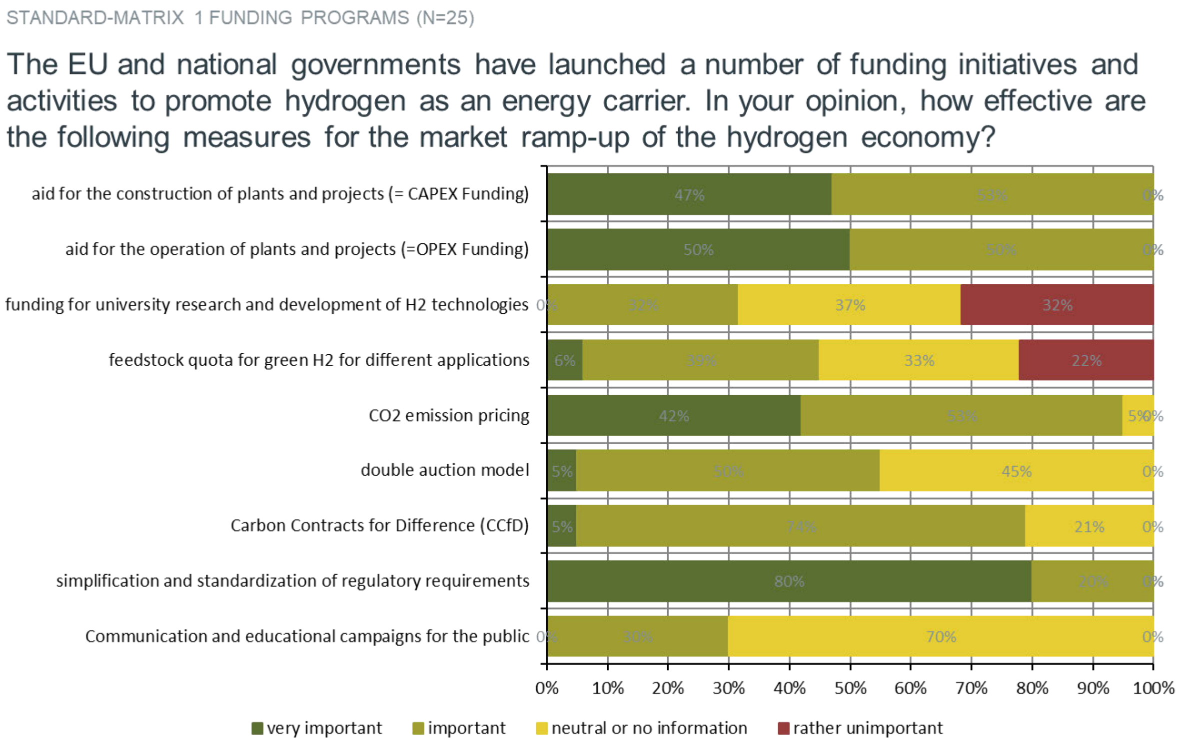

Figure 28 Survey results: Importance of governmental initiatives (author's survey)

Therefore, it is concluded that the EU climate goals and the derived national prescriptions are the most impacting contextual topics, accompanied by the injection of funding money for CAPEX and OPEX and a clear regulatory framework that shapes the market design.

Concluding the survey

In summarising the survey findings, it is evident that respondents express dissatisfaction with both the project progress and the IPCEI process, noting that projects are falling behind schedule. Key factors influencing this sentiment include funding availability, regulatory clarity, and a favourable regulatory environment, along with market demand. Notably, the overarching driving forces stem from the climate goals set by the EU and adopted by national governments. Specifically, respondents identified prominent use cases such as H_2 generation, distribution, mobility, and industrial applications.

This presentation is an abridged evaluation of the survey results; the complete version of the questionnaire and the full results can be found in Appendix 3

5.5. Concluding the chapter: Wrap up phase 1 “screening phase”

The projects and their stakeholders have experienced turbulent times and many changes affecting their projects, e.g. regarding project consortia, financing schemes and scopes. A number of projects have dropped out of the IPCEI funding due to changed criteria by the EU, others have merged. The project progress is far behind schedule, and the stakeholders are very unhappy with EU and national requirements in the IPCEI process; they see those as a burden, not a support. As of summer 2023, only a few projects have received the EU notification and are awaiting national funding approval. According to the author’s best knowledge, hardly any project has made a positive final investment decision to build the projects because viability, markets, regulations, and customers are not settled.

The findings from the screening phase indicate that the business models of the individual projects are less developed than anticipated. Additionally, it appears that external factors beyond the control of the project actors have a more significant impact on the design of the business model than initially assumed. As a result, it was decided to explicitly investigate these external factors in phase 2 and conduct corresponding expert interviews. Consequently, the initial research design was adjusted accordingly.

6. Phase 2 “main phase” findings and results

6.1. Introduction into the chapter

This chapter delves into the analysis and interpretation of the qualitative data gathered during the primary phase of the study. Detailed descriptions of the main phase's design, sources of evidence, and datasets are provided in Section 4.4.4. The datasets are briefly recapitulated below. It is important to note that the raw data, such as interview transcripts, are not included in this thesis. This decision is based on several factors: the large size of the data, its language (German), and, most importantly, ethical considerations to safeguard the anonymity of the interviewees. The transcripts contain sensitive information like project and company names. However, a thorough audit trail for the analysis has been maintained in NVIVO for transparency and rigour. Additionally, the codebook used for theme development is included as evidence in Appendix 5.

The data collection for the “main phase” took place roughly between March 2023 and August 2023 and has produced three datasets (see Section 4.4.4 for details) that entered the analysis in NVIVO:

1. Dataset 1 consists of 16 interviews with project stakeholders. The transcripts comprise a total of 702 minutes of recorded audio.
2. Dataset 2 consists of 17 conference speeches or panel discussions held by project actors or opinion leaders in the H_2 economy. The conference contributions comprise 425 minutes of transcribed audio and video material.
3. Dataset 3: consists of 5 relevant documents, summing up to 116 pages of reports.

The results of the screening phase have led to a refinement of the research questions that guided the main phase. The central research question for the main phase was reformulated as follows:

What business logic* enables viable business models for large scale green H_2 projects?

*****Business logic in this context means the composition of elements into a business model design

Three sub-research questions (RQ) have been introduced to guide the analysis:

RQ1) What elements are the (future) business models consisting of?

RQ2) How are those elements interacting?

RQ3) What business model designs are considered today for upcoming large scale green hydrogen projects?

This chapter provides a comprehensive overview of the coding process and the subsequent thematic analysis. Through this analysis, ten distinct themes have emerged, each directly addressing the research questions. Culminating the chapter is a preliminary thematic map, visually depicting the intricate interplay among these themes. This thematic map is the foundational step toward crafting a novel conceptual framework tailored for business modelling within the H_2 economy.

6.2. Coding the data and developing themes in NVIVO

This section describes how the coding and the theme development were actually conducted based on the method of reflexive analysis. The methodology and the rationale for the approach is set out in detail Section 4.4.4 and is not repeated here.

The three datasets containing 16 interview transcripts, 17 conference contributions and five documents, 38 files in total, were imported into NVIVO (Figure 29).

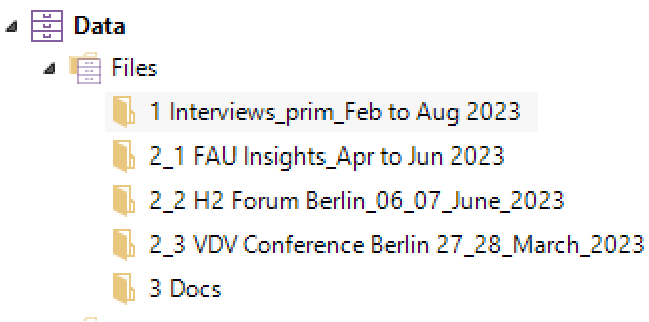

Figure 29 Datasets for qualitative analysis imported in NVIVO (author's own)

Two cycles of coding were conducted: initial coding and second cycle coding. The themes were developed from the second cycle codes. The stepwise proceeding is described below.

During the initial coding phase, the primary focus was preserving all pertinent information within the data while maintaining proximity to the raw data. Given the exploratory nature of the investigation, it was imperative to refrain from premature interpretations and conceptualisations. Hence, each of the 16 interviews underwent meticulous line-by-line coding, resulting in a comprehensive code set comprising 57 distinct codes. Among these, 13 codes were predefined a priori, grounded in the foundational theories of business model designs as outlined in Sections 2.5 and 2.6. The remaining 44 codes were allowed to emerge from the data organically. Employing descriptive coding techniques, as advocated by Miles et al. (2014), enabled to maintain fidelity to the data content and avoid premature conclusions.

After finishing the coding of the primary interviews, the initial code set was copied and named "second cycle codes". This copied code set was then cleaned up, i.e. codes were merged, and simultaneous codes were eliminated as far as reasonable. The codes have been categorised and hierarchically structured. Datasets 2 and 3 have then been coded with this second cycle code set, not line-by-line, but only for information that contributes to the aim of the research and the answer to the research questions. The second cycle code set is presented in Figure 30.

Second Cycle Codes

Name	Files	References	Created On	Created By
Elements of business model	31	250	07.09.2023 10:34	KGB
Business models discussions and design	33	210	06.09.2023 22:32	KGB
Funding, regulatory and govermental info	29	208	06.09.2023 22:30	KGB
Technicals, value chain and general Infos	24	157	27.08.2023 12:55	KGB
Import H2	23	116	07.09.2023 22:03	KGB
(IPCEI) project info (timelines and content)	19	90	26.08.2023 19:24	KGB
Memorable Quotes	27	77	26.08.2023 19:24	KGB
Risks, threats and other disadvantages for Europe and Germany	17	72	06.09.2023 22:07	KGB
Barriers for viable business models	13	61	26.08.2023 19:24	KGB
Drivers for viable business models	15	56	26.08.2023 19:24	KGB
Content of research, further sources and backgrounds	12	40	27.08.2023 12:52	KGB
Future of oil industry and energy genration industry, needs in industries	15	38	26.08.2023 19:24	KGB
Pic of the future	16	30	08.09.2023 22:58	KGB

Figure 30 Second cycle codes NVIVO screenshot (author's own)

The second cycle codes were then the basis for developing the themes and extracting the findings. The development and validating of the themes further followed the approach of Braun and Clarke (2006) and Byrne (2022) as explained in theory in Section 4.4.4 and how it was done in practice is explained in the following.

The primary objective of this study is to delve into the intricacies of business modelling within the context of the H_2 economy. Section 2.4 of the literature review has provided valuable insights into the characterisation of business models, emphasising their constituent elements and dynamic interactions. Moreover, it underscores the significance of activities carried out within these models, which imbue them with operational effectiveness and purpose. Building upon this foundation, the sub-research questions RQ1, RQ2 and RQ3 as introduced in Section 6.1 have been formulated to steer the analysis of the coded data and facilitate the delineation of thematic patterns:

In practice, the next analytical step was to interpret the second cycle codes so that they could be related to those research questions and inform their answers. This was done outside NVIVO in Excel and Word and then re-imported into NVIVO. The following analytical steps were carried out:

1) Exporting the second cycle code from NVIVO to Excel (see Figure 31, screenshot of the first lines of the xls file only) and allocate each code to a research question. Colour codes were used in this exercise for better clarity.

Name	Files (File Count)	References (Code Co	Modified On	
Elements of business model (RQ1)	31	250	07092023 10:33	RQ1
who are customers and markets	17	64	29092023 20:16	RQ1
what is the source of value creation in the BM	15	49	22092023 20:19	RQ1
Who invests and finances	13	41	03102023 11:30	RQ1
what are the product and services	16	37	29092023 19:46	RQ1
which governance structures are in business models	13	26	29092023 19:43	RQ1
which activities are performed in the business	8	15	23092023 18:42	RQ1
Who are suppliers	4	9	07092023 12:52	RQ1
Which assets are in business models	7	9	22092023 13:52	RQ1
Business models discussions and design	32	209	03102023 14:05	
what policies and actions do we see in creating BMs	24	61	03102023 18:40	RQ2
New upcoming actors	13	29	23092023 18:44	RQ1
Old actors with new roles, new BMs	11	29	19092023 10:56	RQ1
Constellations of supplier and customer favorable or unfavorable	12	25	29092023 19:45	RQ3
Explanation of not viable or viable Business model	11	24	03102023 13:24	RQ3

Figure 31 Relating codes to research questions – illustrative excerpt from the Excel export (author's own)

2) Preparing a table template for each research question in Word (see Figure 32, blue lettering label a)). Then, one code after the other allocated to this research question was copied into the clusters of the Word template (see Figure 32, blue lettering label b)). The analytical performance during this step was to analyse if the codes have any commonalities, links or patterns that would justify placing them in the same cluster (see Figure 32, blue lettering label c)). Finally, aggregating headlines for the codes in

each cluster were found. These headlines were the first draft of the themes (see Figure 32, blue lettering label d)).

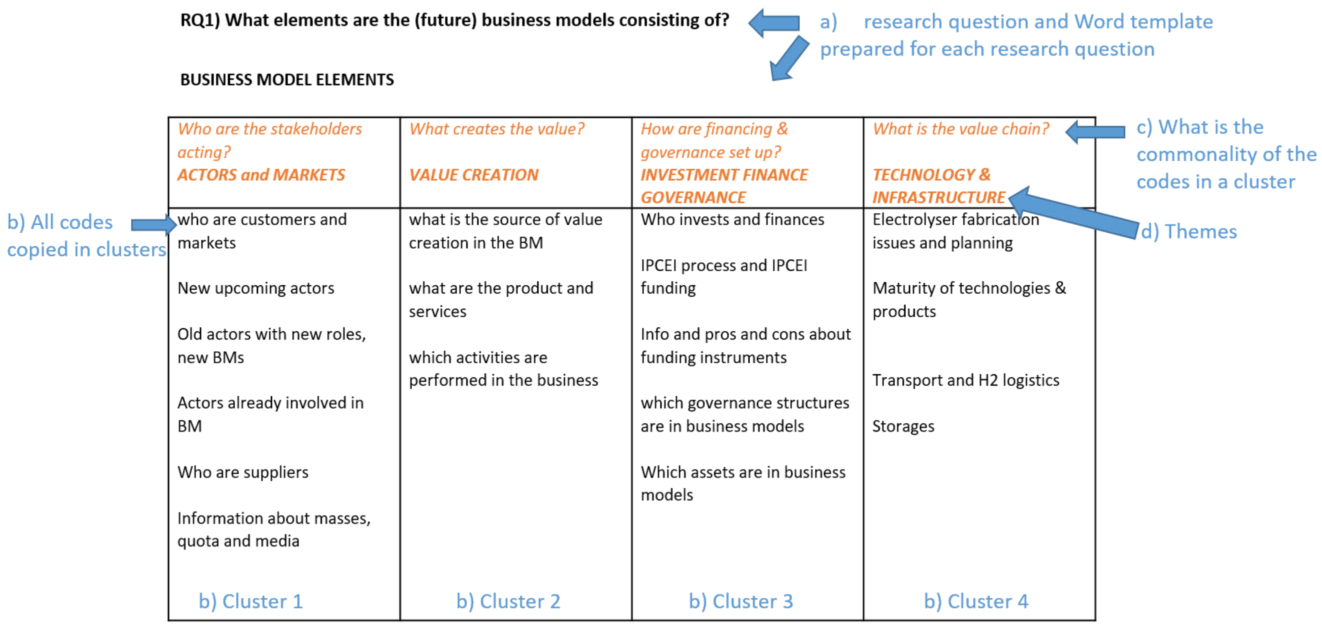

Figure 32 Developing themes from codes in Word (author's own)

3) Next, the existing project in NVIVO has been copied, and the new project was named "Data analysis themes". The initial codes file has been deleted, and the themes have been filled in NVIVO as new nodes. The codes were then dragged and dropped to their related themes according to the Word file arrangement. The result is presented as an excerpt in Figure 33.

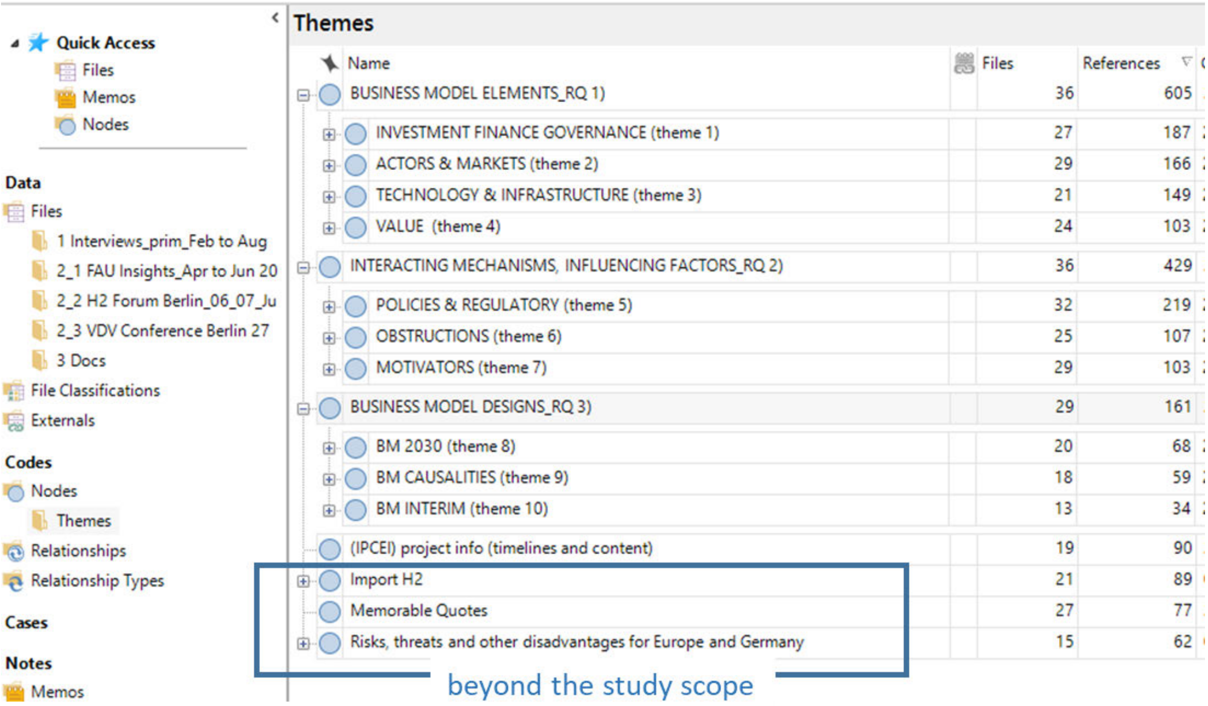

Figure 33 Themes and allocated codes – illustrative excerpt NVIVO (author's own)

Some codes couldn't be directly tied to a specific research question as they extend beyond the scope of the study. These codes, depicted by the blue frame in Figure 33, are retained within the codebook. They serve as valuable input and stimuli for potential future research endeavours, as elaborated in Section 8.5.

This proceeding has the advantage that there is still a direct link from the theme to the original data that will facilitate the authentic presentation of the themes in the next section.

4) The themes and related codes and content were revisited in NVIVO to review their relations and how well they inform the themes. The themes were also reviewed to assess how well they interpret the underlying data and how well they contribute to answering the research questions, following phases 4 and 5 of Byrne (2022).

5) Writing up the codes and the themes. The final analytical step, before producing the report, was an interpretation and write-up of each code's content related to the research questions and related to the theme. The theme narrative was drafted, and the evidence from the data was preselected for this exercise. The write-ups were done in Word. The report for the results then consists of a synthesis of each theme and a summary of the result's overall themes and research questions.

The thematic analysis process was highly iterative and also time-consuming. Analysis and interpretations had to go back and forth several times until the themes captured coherently the data and the research questions and converged into a coherent narrative, which is presented in the next section.

This section has presented in detail the process of coding the data and developing themes in NVIVO. A methodological approach, well-grounded in theory, has been applied following the methodology of Braun and Clarke (2021) for reflexive thematic analysis and the practical example of Byrne (2022). The analysis was conducted with rigour and transparency as explained and documented in this section and in the related Appendices 4 and 5, involving initial coding, second cycle coding, and theme development both within NVIVO and in external tools like Word. The traceability from the theme to the original transcript is kept over all analyses steps. Nevertheless, the potential weaknesses of using NVIVO are acknowledged, such as the possibility of bias in code selection or interpretation, limitations in capturing nuanced contextual information, and challenges in managing large datasets effectively within the software.

6.3. Findings: Business model elements

The following sections present the themes that have been developed from the codes and data to inform the research question, “What elements are the business models consisting of?”. Four themes have been formulated to answer this research question. The themes are presented in their order of dominance, i.e. themes with the most case and code counts are presented first. Each theme is shortly introduced in its definition and meaning and by the codes that inform it. The overall narrative for the theme is presented, and its independence or interdependencies on other themes and other research questions are described. Evidence for the narrative and claims is made by introducing quotes from participant transcripts. As most of the talks were in German, those quotes were translated into English; confidentiality has been protected by allocating the participant identifier (ID) to each quote; for the interview overview, see Appendix 4 .

After presenting the four themes in this way, the business model elements extracted from the data in the themes are summarised in Section 6.3.5.

To easily distinguish the participant, all participant quotes in Chapter 6 are printed in italics. The terms participant(s), interviewee(s), and informant(s) refer to persons who have informed this research, and the various terms are used synonymously.

6.3.1. Theme 1: INVESTMENT FINANCE GOVERNANCE

The consolidation of the three key headings – "investment," "finance," and "governance" – into a single overarching theme labelled as Theme 1 reflects their intrinsic connection to project financing. Although not strictly financial, governance has been incorporated due to its significant role, as evidenced by the data, where funders often hold assets and participate in project governance. This amalgamation encapsulates five distinct codes about funding, the IPCEI process, investors, governance structures, and assets, as detailed in Appendix 5. With 27 file counts and 187 reference counts (refer to Figure 33), Theme 1 emerges as the most pronounced among the four themes pertinent to this research question.

Investment and financing mechanisms are diverse. During a conference presentation by an expert in project finance, a comprehensive account was given about available financing options for hydrogen projects. He explained which kind of project financing models are available, how they operate and what the specific requirements are:

> *Hydrogen projects per se can be financed in different ways. There are actually many common variants. One is classic corporate financing, the so-called on-balance solution, and the other is my topic, project financing. Of course, we must not forget municipal financing. Financing is secured through a municipal guarantee, where a city, district or federal government stands behind it and secures financing. Or as export financing for electrolysers, for example, in this case, of course*. (C3)

However, he and other participants emphasised the favourable nature of project financing for hydrogen projects. This type of financing is typically long-term (often exceeding ten years) and involves establishing a special purpose vehicle (SPV), where the project's investors are likely to become shareholders. Potential financiers include owners of hydrogen facilities, hydrogen customers, investment funds like Hy24, and various funding sources such as IPCEI funding. While most large corporations finance investments using corporate funds rather than external investors, smaller companies tend to rely on multiple funding sources with several partners contributing. All participants see financial risk in the projects that threaten the security of the investment and need to be hedged; as one participant proposes, *"the negative cash flow for the first years cannot be hedged by the investor, and therefore, the government should introduce hedging mechanisms, such as we are familiar with exports in the case of the Hermes guarantee",* (I3). The bank expert further outlined why the financing risk in hydrogen projects is higher than in other renewable projects, such as wind and solar projects.

> *And we also look at, which we did not have to do within the EEG* (author's note: EEG refers to other renewable projects such as solar and wind being funded by the Erneuerbare Energien Gesetz (EEG) (i.e. Renewable Energies Act) in Germany), *is the creditworthiness of our potential buyer. As a bank, we naturally have to look closely at who is our customer for a product, and what is their creditworthiness? This is what we look at in the long term, if this buyer takes us on and we find someone who will buy this hydrogen from us for ten years at a fixed price and then he drops out because he has taken on too much or has other economic problems. Then, of course, we as a bank are faced with the problem of where to put our hydrogen and, if unlucky, there is still no market. If unlucky, there may be no one who can supply us with this hydrogen for the remaining term at that price.* (C3)

C3 elucidates the critical interplay between financing, security, and stability concerning the project's input and output facets. For instance, in the context of a hydrogen project, securing long-term price stability for essential inputs such as electricity and water is imperative. Similarly, on the output side, ensuring stability in quantity and prices for hydrogen offtake is paramount.

All participants agree that state funding will continue to play a major role in the implementation of the projects for the next few years, and all participants also agree that time is an important factor in realising the projects. According to one interviewee, the very lengthy IPCEI approval process seems to be at least partly a German problem, as the following quote states, *"I mean, I'm used to a lot […] but I can tell you that it's an impertinence to wait so long, while other nations, by the way, have already had their IPCEIs ongoing for a long time"* (I15).

Extensive information was also gathered regarding the comparative analysis of the IPCEI funding mechanism versus the US IRA (Inflation-Reduction-Act) mechanism. Many interviewees expressed a preference for the IRA funding process over IPCEI funding. The IRA funding mechanism allows for profit generation by providing subsidies for the produced product (measured in €/kg H_2), enabling projects to construct their business plans around the quantities of hydrogen they produce and the corresponding subsidies they receive. This model incentivises higher production volumes, resulting in increased subsidy payments. As a result, a viable business case can be meticulously calculated. While the comprehensive dataset could not be entirely incorporated into this study due to space limitations and the study's specific focus, the primary insights gleaned from the interviews are summarised below, accompanied by pertinent quotations.

I12 explicates on the planning reliability of the IRA mechanism: *"This creates a certain planning reliability for investors and business planners that an IPCEI process does not. And as a result, a generally applicable subsidy attracts much more private investment than a case-by-case subsidy like IPCEI"*, (I12).

I1 complains about that IPCEI does not incentivise profitability:

> *This IPCEI mechanism even provides for a draw-back mechanism. So, if we were more profitable than we assumed at the time, or generated more than our*

> *capital costs, let's say, we would even have to pay back the subsidy, so in principle the IPCEI process already provides a certain framework within which this will probably move. So it will not, cannot be, overly profitable.* (I1)

I16 summarizes the differences of IRA and IPCEI as follows *“while one wins positively in the business plan, technically evaluated, the other is just, I call it kindly a pain relief in the cost”*.

Summarising what has been said, the participants see a problem in the fact that IPCEI, unlike IRA, does not promote the emergence of a liquid market and is lengthy in its process and complicated. Therefore, the participants request that a combination with other funding instruments be allowed, in particular, a combination with OPEX funding, i.e., operating cost funding. The H_2 Global initiative, the European Hydrogen Bank, the Innovation Fund, the Green Deal (2019) and the RePowerEU (2022) program were mentioned in this context (see Section 2.4.4 for a short introduction of those policies). These topics are regarded as influencing mechanisms rather than business model elements for this study and are therefore presented in more detail in Section 6.4.

Governance structures seem to vary across projects. In some cases, customers are also shareholders, which seems beneficial for the hydrogen producers as they gain insights into customer requirements. The customers’ interest in holding shares in the venue is to secure H_2 supply security.

During the course of the project, there could be shifts in the shareholder composition, influenced by partners' priorities and project outcomes. Suggestions have been made to potentially involve the government, i.e. the state more prominently as a shareholder and regulatory authority. This involvement aims to guarantee fair hydrogen pricing, facilitating a sustainable business model. For instance, the engagement of ports in

Northern Germany serves as a potential model, as ports are state-owned. However, it is anticipated that EU regulations and competition laws will ultimately steer the hydrogen economy towards a free market structure in the long run.

One participant, I14, reflected on the type of governance and the degree of integration of other value chain steps, asking, *“Does, e.g. the electricity supplier already think about building the H_2 plant or not?”* Sometimes, only the financier and the H_2 plant operator invest and decide about FID (financial investment decision). For smaller companies, having an investor with governance in the project is welcome; I5 states, *“…good financiers are also acknowledged for the quality checks they do on the business model”*.

Some projects have quite a high number of shareholders at the beginning, for example, more than five shareholders. This is particularly the case when the project implementing company is rather small and relies on many financiers.

The data generally supports the statement that the appetite to invest in the field of hydrogen is high, but also acknowledges the threats of risk and costly investments, which negatively impact the expected return on investment. These aspects are also summarised in the McKinsey Report (McKinsey, 2023):

> *Climate technology companies should have a clear path to reach de-risking and growth milestones that help them build a balance sheet that expands to include lower-cost equity, project finance, and debt at scale. This factor will be particularly critical for capital-intensive climate solutions (such as hydrogen, carbon capture, and battery manufacturing) that require raising significant capital, building many first-of-a-kind facilities and projects, and educating investors and lenders to realize their scale aspirations.* (D4, p.11)

This account presents the narrative synthesised from the data's main topics, i.e., investors, major funding sources, governance and assets. Due to the importance of funding programs to raise money for the projects, this theme strongly links to themes 5 to 7, presented in Section 6.4. The identified business model elements of Theme 1 are collected in Table 7 and sorted into different hierarchical layers. The “Dimension” layer describes and numbers the overarching elements that the participants named; for theme 1, these were three dimensions: “Governance”, “Invest & Finance”, and “Time”. For each dimension, several parameters could be extracted from the data showing the dimension range. For example, in Table 7, dimension 1, “Governance”, could be executed by a joint venture, sole owners, government, etc. Table 7 provides a third layer of information named “Characteristics, Features, Choices”. As far as those were mentioned by the participants, they were noted in the related columns of Table 7; they inform about which concrete business model design choices might be available. The entries in red in Table 7 mark surprising findings. These are referred to as surprising findings, since they refer to unexpected or unconventional results discovered during the study. These findings are remarkable because they were not to be expected from the results of the literature research. They are further discussed in Chapter 7.

6.3.2. Theme 2: ACTORS & MARKETS

Theme 2 contains the synthesised information that was given to actors and markets. The two topics are considered together because the actors co-develop and significantly shape a market that does not yet exist. This is a big difference from other existing liquid markets, where players who want to participate have to think about market entry strategies and unique selling points. Six codes about customers, market sizes, new and old actors and suppliers contribute to this theme. It is the second most dominant theme, having 29 file counts and 166 references assigned to it (see Figure 33). The following account summarises, synthesises and interprets what can be taken from the data collected. Significant statements are supported by translated original quotes from the participants.

In general, there is a unanimous consensus among all participants regarding the exceptionally high demand for green hydrogen in the foreseeable future. The spectrum of potential customers for green hydrogen is vast, encompassing industries such as steel, refineries, cement, glass, ceramics, and various sectors, including mobility and maritime. Furthermore, there is an emerging discussion about the potential utilisation of hydrogen in the heat sector. Additionally, hydrogen's role as a storage medium for electricity during periods of high renewable energy generation in the grid is also being actively deliberated.

However, the development of these markets faces various challenges, not only originating from high costs. The following quotes illustrate the issues raised by the participants:

I13 mentions willingness and ability to pay: *"So demand is there, but not at the price we can provide it"* (I13).

I16 criticises the lack of a market design and, consequently, a lack of demand, *"so we don't have a market design that opens up a real, market-based demand or the will to create a supply. There is an absolute default"* (I16). I16 also elaborates on the potential consequences for Germany as an industrial location. *"Manufacturer A* (author's note: information disguised due to confidentiality), *who just decided, and I definitely know* *that they were already looking at the German market as a production location on the map, has now announced that they will build a Gigawatt factory in America",* (I16).

I3 points out the absence of regulatory frameworks, which also hinders the development of a market: *"In addition to funding for the infrastructure and for individual projects, they need an overall setting of framework conditions so that a demand for hydrogen arises in general….... one needs to speak about capacities with customers"* (I3).

So, willingness and ability to pay, lack of market design, lack of capacity planning, what would be needed to decide on building the hydrogen infrastructure and threat of de-industrialization of Germany have been mentioned as major blocking points for the faster development of the H_2 market.

However, the first attempts to facilitate market development are in place. The steel industry seems to be set as a pioneer; for example Salzgitter Steel has announced to invest 1.5 billion € and additionally receives 1 billion € funding (SalzgitterAG, 2023). It is hoped that these activities will create a lead market for green steel, which then provides a kind of base supply and base demand, which other users can then join and further build up the market.

Thanks to the quota obligation outlined in REDII (Renewable Energy Directive), there is a clear imperative for the mobility sector and fossil fuel refineries to reduce carbon content in their fuels. This aligns with environmental goals and provides a tangible motivation for embracing green hydrogen. Furthermore, various forthcoming initiatives such as RED III, Carbon Contracts for Difference, IPCEI, and GEG are poised to support other industries in similar endeavours. Section 2.4.4 offers a concise overview of the ongoing discussions surrounding these programs and directives at the EU and national levels.

It was emphasised by several participants that for economic reasons, the projects need to be big, such as installing electrolyser capacities of at least 20MW, better 100MW, and more. Industrial customers with high hydrogen demand are needed to consume these amounts of hydrogen. There is also a need for hydrogen infrastructure, for example, via pipelines between the supplier and the customer. I12 pinpoints the infrastructure as a key element for developing a market design of supply and demand:

> *It doesn't help, so to speak, if you only start on the production side or only on the demand side. We need infrastructure in between. Otherwise, it won't work; only through structure has natural gas somehow become affordable and useable in a meaningful way, and it's the same with hydrogen. A competitive target price could be in the range of 3,5 to 4€ per kg hydrogen*. (I12)

Understanding the potential market size is pivotal in crafting effective business models. Numerous studies have delved into forecasting the market size for green hydrogen, a critical aspect of the renewable energy sector. The data collection process encompassed attending various conferences (dataset 2), where insights regarding the potential market size were shared. It is important to note that market data pertaining to the hydrogen sector typically spans a range and undergoes continual updates. The figures presented herein encapsulate the expert consensus as of summer 2023, drawing from diverse sources within dataset 2:

- for Europe in 2030: 20 million metric tonnes per year, thereof 10 million tonnes domestic European production + 10 million metric tonnes import H_2 per year (C10, C11)

- for Germany in 2030: 90 to 110TWh of green hydrogen and derivatives per year (C2) (author’s note: 100TWh corresponds roughly to 3 million metric tonnes of H_2)

In summary, the experts agree that huge amounts of hydrogen will be needed to decarbonise the sectors and the industry to net zero emissions in 2050, as is required by the European Green Deal (EC, 2023d). As not all this green hydrogen can be produced domestically in Europe due to a lack of renewable energy, the hydrogen will have to be imported from countries with favourable conditions for renewable electricity generation, such as Australia or Chile. For Germany, an import quota of about 50% to 70% is predicted. Although many contributions were made by the participants on the topic of hydrogen imports and their related impact on the German industry, it is impossible to go into more detail here because this topic goes far beyond the focus of the study. These topics will be subject to the next research (see Section 8.5).

Since there is currently no global market for green hydrogen and no large-scale production plants or existing transport infrastructure in place, there is a lack of transparency regarding potential market prices. Consequently, participants did not provide information about the market size in euros. However, understanding the financial scope of the market is crucial for business model design. To estimate the financial size of the green hydrogen market in Germany, the author used information provided by I12 (see above), indicating a price of 4€/kg (equivalent to 4000€ per tonne) and an estimated 3 million metric tonnes in 2030. Based on the author's approach, this suggests a minimum annual market value of 12 billion € from 2030 onwards.

The burgeoning green hydrogen economy has become a magnet for diverse participants, ranging from newcomers to established industry players adapting their roles to this transformative landscape. Within this dynamic arena, numerous opportunities beckon those with interest and ambition. Roles abound, spanning from being a customer, investor, or equipment supplier to becoming an H_2 producer or transport provider. What sets this ecosystem apart is its remarkable flexibility. Companies can navigate between roles within a single project or transition between different projects altogether. For instance, a steel company might initially serve as both a customer and investor, eventually evolving into an H_2 producer through onsite production. Similarly, a supplier, such as an electricity provider, could pivot to become an H_2 supplier by operating an electrolyser plant and selling the produced H_2. This fluidity fosters a vibrant and inclusive atmosphere within the hydrogen sector, paving the way for innovative cross-sector collaborations and business models that open doors to fresh opportunities.

Such cross-sectoral new combinations of business ideas are already emerging, and different interviewees have given examples. I9 describes the idea that an industrial hydrogen consumer builds onsite electrolysis and uses this onsite electrolysis also to offer flexible load to the grid: *“For example, if an industrial company builds an electrolyser onsite next to the factory and possibly couples it with a storage facility and so on. These would certainly be a newer concept”*, (I9).

Another interviewee sees automotive companies also offering and operating charging stations for electric cars: *“But the idea that OEMs, i.e. original equipment manufacturers* (author’s note: i.e. automotive suppliers*) will develop and also operate charging stations themselves, … that will certainly also happen in the wider area of the* H_2 *economy. I think that's perfectly fine”* (I15).

Further examples have been presented at the various conferences and are shortly summarised below:

- An insurance company (DEVK) founds a company that rents H_2 trucks (C13)
- A public transport company and an energy company collaborate to produce green H_2 and run H_2 busses for public transport (C14)
- Everfuel, a start-up offering serving the complete value chain from H_2 generation over transportation to H_2 use (for industrial applications and mobility) (C15)

Participants are looking forward to the continued presence of diverse actors and the emergence of fresh business partnerships, especially in the early stages of the H_2 economy. As the H_2 industry transitions beyond this initial phase, a consensus emerges among many participants that a period of consolidation will ensue, with greater attention directed towards larger, well-established companies. This shift is rationalised by the significant capital investments demanded, a realm where only financially robust enterprises can effectively engage. Moreover, established companies are spurred to explore innovative business frameworks driven by the waning viability of their traditional fossil energy-centric models. This sentiment finds resonance in the following quote:

> *But it is actually the case that the actual energy companies also have the most backing, i.e. they are struggling financially and, of course, also for survival. So now the gas industry is sitting on its gas grid, which is now almost paid off and now it may be obsolete. Of course, then you suddenly have other room for manoeuvre and other desperation, which then drives you to implement something hydrogen-based.* (I13)

In general, the participants agree that the large incumbent companies, such as Siemens, Thyssen, and Linde, play an important role in the equipment and plants and that the large energy companies, such as RWE and Eon, Uniper, Shell, BP, Total, and VNG, play an important role as operators.

But medium-sized newcomers, such as McPhy, Sunfire, and Elogen as technology providers and Enertrag, GPJoule, and EWE as operators, are also acknowledged to play a role in the market, at least during the ramp-up phase.

What the diversity of actors and roles look like in the long term seems to be unclear today, which becomes obvious in the following quote: *"If you look at who is affected by the issue* (author's note: i.e. hydrogen economy) *and who can potentially play a role. It is not clear today who is best positioned, so to speak"* (I12).

This section reports on the actors and markets in the emerging hydrogen economy; it reflects the situation as of summer 2023. The formation of markets for use cases and industries co-depends on the regulatory settings and incentives given to industries to decarbonise; therefore, this theme also has strong links to themes 5 to 7, which are presented in Section 6.4. The theme also links to theme 1 as the financiers are also actors that could also take over governance in the projects. The identified business model elements in their dimension, parameter and characteristics are compiled in Table 7. Remarkably, one actor can have multiple and interchangeable roles from project to project, this is noted in red in Table 7.

6.3.3. Theme 3: TECHNOLOGY & INFRASTRUCTURE

Theme 3 offers valuable insights into the technical maturity and design of products essential for a hydrogen economy. In alignment with the broader scope of the study, this theme directs its attention towards infrastructure and hydrogen generation. It is important to note that while the significance of technical contexts is acknowledged, the primary emphasis remains on exploring various business models. Thus, technical aspects are introduced only to the extent necessary to illuminate their implications for the business model landscape.

Four codes about technical issues and maturity of products and technologies in the fields of hydrogen transport, logistics, storage and electrolyser manufacturing inform this theme. The theme has 21 file counts and 149 references assigned to it (see Figure 33). The following account summarises, synthesises and interprets the related information taken from the data collected. In the following account, the word "grid" is used for network, typically referring to the pipeline network for the transport of gases in this section. Sometimes, "grid" means the electrical power grid; the relevant meaning is evident from the context or is given by additional terms.

All participants agree that the hydrogen infrastructure for transporting and storing hydrogen is the most important prerequisite for ramping up the hydrogen economy. It seems clear that the large amounts of hydrogen needed for industrial processes cannot be transported by trucks to the sites of industrial customers. The participants made many comments in this regard; the following examples illustrate this. I12 and I13 put forward that a missing infrastructure for hydrogen transport is a showstopper for the H_2 economy, and care must be taken to offer access to green hydrogen for smaller companies.

> *"What you must not forget is that hydrogen is a gas and, like gas, it needs infrastructure to move from supply to demand."* (I12)
>
> *"We must somehow have at least one transmission grid, preferably a European one. And maybe also distribution grids, because our entire SME (author's note: i.e. small, medium enterprises) sector depends on the distribution grid, otherwise they won't get any hydrogen at all, and then?"*. (I13)

I13 sees the necessity of the hydrogen grid as a means for large-scale electricity storage and, therefore, as a means to balance intermittent renewable electricity generation.

> *"I believe that the infrastructure is an important prerequisite and also for our entire de-fossilisation of the electricity system, to make the whole thing stable, to compensate for fluctuations or to overcome dark lulls (i.e. times with no wind and no sun), we also need hydrogen in a relatively large-scale production and also in a large storage system."* (I13)

According to associations and experts on the natural gas grid, Germany seems to be in a lucky situation to be able to convert parts of the existing natural gas grid relatively easily into a hydrogen grid, at least technically. During a conference, C5 explains the main differences between the transport of natural gas and the transport of hydrogen and concludes that conversion of large parts of the grid seems possible:

> *The calorific value of hydrogen is approximately 3.5, and for natural gas, it is 11. So, the heat content is 3.5 times lower. Theoretically, do I have to send more through the grid? If we now have the same quantity and we say that the current natural gas network is the same as the hydrogen network, yes, it is possible; the flow rate is just significantly higher, and then you need other compressors (…) compressors, as we say, in the gas. But it works.* (C5)

He elaborates on the materials used for the German gas grid's pipelines, which are not susceptible to embrittlement, so only 0.2% of the pipes would have to be replaced. A project actor from one of the H_2 logistic projects points out that administrative requirements must also be met before the network can be rededicated. The related pipes have to be delisted from the official gas network plan, *"If the decision is negative,* *i.e. this infrastructure is no longer needed for natural gas supply tasks, then you can do what you want with it. Ultimately, we want to use it for hydrogen transport"*, (I3).

The planning of the dimensioning of the transport grid seems to be difficult, as it is unclear when, where and how much hydrogen will have to be transported, following I3, who says, *"I believe that the framework conditions for a project pipeline that is secure for generation are also relatively unclear. That's why we are planning to diversify between imports and the integration of national generation projects"* (I3). What seems clear is that certain prioritised industries, such as the steel industry, will be connected first.

The goal is to offer reasonable proximity to the gas grid to all projects that want to connect. As I15 phrases it, *"to give all regions in the north, west, south and east the prospect of having a pipeline nearby in the near future, so that they can realise their projects"* (I15).

As mentioned in the literature review (see Section 2.4.4), the DVGW has provided a Gas Transformation Plan including a timeline and a database (verifHy) where project actors of hydrogen logistic projects can send their requests regarding the usability of their existing pipes and their grid they want to convert to hydrogen and ask for a check for hydrogen readiness. C5 stated during a conference:

> *In other words, I want to convert the grid here in different phases. So sometimes, there are mixed areas where you mix hydrogen. There is also an initial situation here, for example, where someone may already have a sub-grid where hydrogen is supplied locally. And so, I have to convert this bit by bit until I have converted almost everything by 2045.* (C5)

These explications given by different participants all seem good; however, it seems to be less known amongst the actors, as the impression of some participants is that *“there is simply a lack of any kind of clear target or plan”* (I8).

Storages are also believed to be essential for the ramp-up of the H_2 economy. In this regard, Germany seems to be in a similar good starting position for converting the gas grids. Experts agree that salt caverns are a good way of storing large quantities of hydrogen. Germany, particularly Northern Germany, is equipped with many caverns that today store gas but are, in principle, suitable for storing hydrogen. According to some interviewees, Germany has a good possibility of generating business from this by storing hydrogen, not only for German use but also for other countries, just as Germany does for natural gas. I3 notes, *“If the hydrogen economy takes up in Europe, we will simply be the hydrogen storage centre for the European market”* (I3). This potential income source is also listed in Table 7.

From a technical and administrative standpoint, converting caverns currently used for natural gas storage parallels the process of converting the gas grids. Both require technical adjustments and administrative re-evaluation. Furthermore, it is imperative to acknowledge the critical observation made by some stakeholders: preparing new salt caverns for hydrogen storage is a time-consuming endeavour, spanning several years with multiple essential steps. Thus, initiating this process promptly is paramount, meaning the time to act is now.

When discussing the storage and transport of (gaseous) hydrogen, hydrogen derivatives or hydrogen carriers are always discussed. The experts’ opinions on this topic are not unanimous. Some see a bright future for the derivatives, particularly green ammonia, as the industry is used to shipping and handling ammonia. This was expressed during a panel session by C9, who sees ammonia *“as a reliable workhorse”* where also the handling is familiar and available as C9 emphasises, *“We have done (this) for quite a time in humankind and using existing infrastructure, not just a use of some few LNG terminals but use the oil infrastructure daily”,* (C9).

Others see the use of ammonia as more critical, as there is a high energy demand during the cracking process. Furthermore, they see a lack of technical maturity in the ammonia cracking process, which needs to be performed to unbind the hydrogen molecule from the nitrogen molecule.

In general, pipeline-bound hydrogen transport seems more practical because it can be used directly. In contrast, shipping becomes relatively cheap for large distances and seems to be without alternatives when it comes to overseas transport, e.g. importing hydrogen from Australia or similar distances. C2’s quote summarises the situation around the transport and logistics of hydrogen:

> *This means that there is still a lot to do here, but at the same time, there is also little flexibility, planning processes, long approval processes, and, honestly, little experience in using hydrogen on a large scale. As I said, we are at the beginning of a long journey*. (C2)

Electrolyser manufacturers are also affected by the chicken and egg problem, and there is no market yet. Still, large orders and planning security are needed to ramp up the electrolyser production facilities and to be able to valorise scale effects and also to build up knowledge; I8 recalls the shortcomings related to large-scale production:

> *You hear that from the electrolysis manufacturers; of course, they already have experience in electrolyser production, but not on such a large scale. They don't have enough experience, so that's a point that it will take a while to really build up that much.* (I8)

Another issue that is being viewed with concern is the time factor and the related threat of Germany and Europe being too slow in building up capacities and being overrun by the global H_2 industrial competition. The electrolyser production capacities, the so-called gigawatt factories, are currently being built but are not yet operational. One of the interviewees expresses this:

> *I don't expect this gigawatt production to be available by 2026 on the scale that projects have been announced. Because somehow, over 20 gigawatts have been announced for Germany alone with all the expansion stages, and most manufacturers want to reach a gigawatt scale in production by 2030. And then we just covered 5 or 6 gigawatts. It just doesn't fit together.* (I13)

Generally speaking, the maturity of technology and products for the hydrogen economy is a topic of debate among the participants. Some, including representatives from associations, politics, and finance, believe that the industry is ready for the market:

> *I would say that we have completely covered the value chain. In terms of utilisation, we certainly need to look at different fields of use. But I would say that we are ready-to-market, so to speak, in primary energy generation, renewables, then electrolysis, transport and storage*. (I16)

However, they acknowledge that there are still areas that need development, particularly in process applications to be converted to green hydrogen.

Others, including those directly involved in projects, express more scepticism about the maturity of the technology. They note technical problems and risks that could lead to cost increases. Listening to project actors there are voices saying *"it's not just like that, you buy something, it stands and works"* (I5) and *"the technical problems, the* *technical risks, they are still to come, they will still lead to cost increases"* (I3). They also highlight a high risk for investors if large projects fail due to technical shortcomings. Despite this, they admit that some aspects of the technology's maturity may need to be glossed over to secure positive investment decisions.

Moreover, there are notable apprehensions regarding the entirety of the supply chain, spanning from electrolyser production to component delivery. Presently, fabrication processes for electrolyser stacks lack automation, resulting in limited quantities being produced. Compounded by the scarcity of operational projects, a deficit in accrued operational expertise exists. Notably, concerns have been raised regarding spare part supply and its availability, as highlighted by stakeholders involved in the projects. The uninterrupted availability of the plant, and consequently, the assurance of a continuous supply of hydrogen, holds paramount significance for industrial consumers. In a conversation relayed by I5, one of their industrial clients emphasised the criticality of plant availability for their operations:

> *[…] and please make sure that you have this (*i.e. spare part supply*) under control because if our plant doesn't get any hydrogen and when we have to shut down, it won't take 14 days, but 10 days until we're fully up and running again and that's really, really expensive.* (I5)

Project owners face a pivotal decision when shaping their value configuration model. This entails determining the degree to which they wish to oversee and harness value, as well as their desired level of involvement in technical intricacies and the knowledge they aim to acquire. Maintaining autonomy and minimising reliance on suppliers is a paramount concern for many venturing into the H_2 industry. As one project owner underscores, maintaining command over technical performance stands out as a pivotal priority for them:

> *Exactly, if someone offers us a turnkey in a container, we will definitely not buy it. Because that's exactly this keyword, what they all say we offer turnkey solution, it only needs water and electricity and exactly then we give up the complete control and the efficiency.* (I5)

This section has presented information on technical topics and perceptions of the maturity of the technologies and products. In case of divergent opinions about certain aspects, both were presented within the account. As for the other themes, the business model design elements are extracted and listed in Table 7. The dimension of value configuration that comes up within this theme (see above) has been sorted to theme 4, “VALUE”, and is listed at the bottom of Table 7. Compared to business models in other industries, it was surprising that aspects around technical maturity and availability could be considered elements of the business model design. Furthermore, it was found surprising, that they seem to play such an important role, therefore it is written in red in Table 7 and is further discussed in Chapter 7.

6.3.4. Theme 4: VALUE

In this study, "VALUE" is broadly defined. Theme 4 encompasses synthesised information on value creation, capture, and proposition. It includes three codes detailing the sources of value creation, such as which products, services, and activities generate value in hydrogen generation and logistic projects. The theme comprises 24 file counts and 101 (see Figure 33). The following account summarises and interprets the collected data, supported by original quotes from participants. Table 7 contains business model elements and their characteristics extracted from the data. Analysis reveals numerous possibilities for value creation in projects, but accessibility and feasibility depend on the project's context and environment. Pricing and regulatory issues remain uncertain. One source of value creation is through hydrogen transport, with projects aiming to profit per kg, kWh, or km distance by paying grid fees. Another potential source is the grid connection fee, although a wide price range is under discussion within the experts' community. An interviewee cited a discussed price range for transporting H_2:

> *I've heard several numbers now, the last from €0.10 to €0.30 cents per 1000 kilometres. I think that's good, but I've also heard one euro, which I found a bit frightening, so yes, if you have to pay €0.10 per 3000 kilometres in the pipeline, that's very good, if it's one euro per 1000 kilometres, that's very bad.* (I5)

Again, others say that the transport costs for hydrogen or its derivatives are not the problem and also not too costly when imported:

> *So, in such a fully organised trade, where it is simply common practice to ship these substances across the world's oceans in a climate-neutral way, transport costs are not the problem. So the likelihood of importing even from countries far away is not exactly zero, but on the contrary very high.* (C1)

The approach to creating value by transporting hydrogen via the gas grid should mirror fossil gas transport, employing an entry-exit system. In essence, an entry-exit system entails the transmission gas grid operator providing capacities that can be reserved by parties seeking to utilise the grid for hydrogen transportation. However, a significant challenge for stakeholders engaged in transport and logistics projects lies in establishing the operational framework for such a transmission model during the initial ramp-up phase, especially when only a handful of off-takers are connected. Clear and robust framework conditions are essential to mitigate the effects of this ramp-up period and ensure a smooth transition. An interviewee (I3) from a transport & logistics project phrases it as follows, *"how is a balance established between the network operators? The profiteer who only has a short line to build, let's say 10 kilometres, and then he has the biggest customer",* (I3). The project stakeholders are not clear about how and when the transport of hydrogen can become a new business field for them; this is due to unclear regulations and during low usage factors of the grid during the ramp-up phase, which impedes profitability, as explained by an interviewee as follows:

> *This means that there is always a profitability gap. That's why we write all these applications. However, there is still no regulatory definition of how this profitability gap is to be covered, how the business cases for the grids are to be calculated. It is unclear what the regulation for transport and for the distribution grid should look like. […] In other words, our goal is for the hydrogen grid to ultimately be financed via grid fees, just like the gas business.* (I2)

For hydrogen generation projects the main source of income is obviously the sale of hydrogen. But the pricing cannot follow market rules because there is no market yet. This means that hydrogen providers and hydrogen customers cannot negotiate a price. Project actors do not have a clear idea of how they can obtain an adequate price for their offer.

The following quotes from I6 illustrate this, *"then we were told that we would first orient ourselves to the order of magnitude of grey hydrogen"*, (I6). I6 goes on and reproduces a conversation with a customer who told him, *"my process does not allow the hydrogen to be purchased at such a price* (author's note: i.e. to purchase green H_2 at a higher price than grey H_2)*, then I say okay, this delta, I am claiming it as a delta. I would like to be reimbursed by the state."*

In this quotes I6 refers to the price building models, such as the H_2 Global concept and the CfD, Contracts for Difference idea (see Section 2.4.4 for more information). H_2 Global is a marketplace that interacts as an intermediary and decouples production from consumption and can also buffer the price differences. Generally, the H_2 Global model is seen as a good start for the ramp-up of the H_2 economy, because it ensures off-taking for the producers and it ensures security of supply of H_2 for the off-takers. The H_2 global mechanism should also help to gain knowledge about the prices and to constantly collect the price signals from the producer and the consumer site, *"what are the prices at which hydrogen can be offered to us? And what are the prices that our industrial customers are prepared to pay for hydrogen?"*, (C1).

A number of other, add-on income opportunities were also mentioned. These are seen as additional business rather than the main business.

For example, providing grid services to the electrical grid and participating in the trading market, such as day ahead market or intraday market. The electrolysers can participate in the (electrical) grid balancing market and be offered as flexible load. Depending on the needs in grid balancing this offers access to very cheap, sometimes even negative electricity prices, in certain times. Some projects also plan with this value stream for their business, *"with a planned base load (of hydrogen production), we can cover this, via direct connection and PPA* (author's note: PPA means power purchase agreement)*, but we can also produce hydrogen really cheaply via this reserve energy market"* (I5).

ETS (Emission Trading System) Trading, as elaborated in Section 2.4.4, presents a viable avenue for generating supplementary income, particularly for selected industries and clients. For instance, companies opting to replace grey H_2 with green H_2 in their operations witness a reduction in their CO_2 footprint, subsequently diminishing the need to purchase as many CO_2 certificates as previously required, thus leading to cost savings. However, it is important to recognize that both revenues from the balancing energy market and those stemming from ETS are contingent upon market fluctuations and cannot be unequivocally relied upon as a stable income source for the business endeavour.

H_2 clusters and local H_2 hubs, presented in Section 6.5, also offer additional income sources by trading and sharing of resources amongst the partners. Some participants mentioned that they offer “all in one solution”, that means e.g. not only the sale of H_2, but also the erection and operation of the hydrogen refuelling station, this also generates extra income streams. The emergence of local H_2 clusters and the emergence of value chain integrated offers is explained in more detail in the next section.

Two more, less known and conversely discussed applications of hydrogen suitable to generate income, mentioned by the participants, should be briefly noted here. First, the burning of hydrogen to generate heat, was discussed controversially, because it is far more expensive than burning gas or oil but it has become more acceptable since the stop of the Russian gas supplies. C5 sets this out in the conference presentation:

> *If I look at the figures here, 49.5 % currently heat with gas and 24.8 % with oil. So if you add them together, that's 75%. I don't think we can do it entirely with electrons, but hydrogen clearly has to make its contribution here*. (C5)

Additionally, there are opportunities for handling and further processing hydrogen derivatives, including substances like ammonia, methane, and methanol. These derivatives can be produced using green H_2 outside of Germany and then transported into the country for further refinement, either to extract the hydrogen again or for other industrial processes. This presents a potential avenue for business growth within Germany.

While Table 7 may suggest numerous revenue opportunities for H_2 projects, it is important to note that achieving a positive business case at present is extremely challenging. This difficulty is also why almost no positive final investment decision (FID) has been made for these projects to date. This section closes with two more quotes that illustrate this situation. According to I3, it is necessary to monetise additional value streams, as profitability will otherwise become difficult:

> *Where not only the hydrogen comes out of electrolysis, but also heat and oxygen need to be used, i.e. more electricity, value-added things. For me, these are the competitive issues, so I personally consider electrolysis purely for the sake of electrolysis to be difficult in terms of competitiveness.* (I3)

The chicken and egg problem in terms of supply and demand and the lack of infrastructure is raised by another participant, C8:

> *Still, it's not that easy. If you go to the off taker side to really get signed contracts today because we are not able to guarantee volumes and prices right now and an off taker obviously is not willing to sign a contract without having a price and the guaranteed volume, there. So in an iterative way, we have to start from talking to MOUs* (author's note: <u>m</u>emorandum <u>o</u>f <u>u</u>nderstanding) *to kind of certain pre contracts and to step by step working to do this. But I think the pressure on the off taker side is high enough to kind of encourage them to make bold steps as well.* (C8)

Table 7 shows the elements extracted from theme 4 that are relevant to the design of the business models. Again, red comments indicate surprising findings, which will be further discussed in Chapter 7.

6.3.5. Summary Findings for Business Model Elements

The preceding sections have delved into narratives about themes 1 to 4, shedding light on how various project actors and stakeholders perceive the dynamics of the H_2 economy. Extracted from these narratives are elements of business models, meticulously organised into dimensions, along with their corresponding parameters and discernible characteristics. This wealth of information has been meticulously compiled into a comprehensive table. This table encapsulates ten distinct business model dimensions, spanning from "Governance" to "Value Configuration," encompassing over 43 parameters, that were mentioned by the participants as how the business model dimensions could potentially be conceptualised. The column labelled as “Characteristics, Features and Choices” contains the collection of elements mentioned by the participants, how the individual parameters can be designed or what could belong to the individual parameters. For example, the first line of entries in Table 7 means: The “Governance” of the business model could be organised as a “Joint Venture” and potentially “Customers”, “Investors (banks, investment funds) and “Government / state owned” could be involved in this joint venture.

Table 7 serves as a repository of insights into the myriad design options available for crafting business models tailored to the demands of the H_2 economy. While it is important to note that this table may not be exhaustive or infallible in every aspect, it offers a sweeping overview of the expansive landscape of possibilities in business model design within the realm of the H_2 economy.

Some entries in Table 7 are written in red, they indicate “surprising findings”. A finding was labelled surprising if it could not be expected from the knowledge gained from the literature search or from the author's expertise.

Generally Table 7 presents the results of the phase 2 data collection. Explanations and interpretations are given to aid understanding of the table, interpretations and further analysis of the collected findings is presented in Chapter 7 and how the results can be practically applied is presented in Chapter 8. In Chapter 7, the discussion chapter, the business model dimensions, entries in bold in Table 7 are used for the development of the conceptual framework and the entries in red are further discussed. Furthermore, Chapter 7 interprets and discusses the meaning of Table 7 in detail and the conclusion chapter, Chapter 8, Section 8.2.2 provides a detailed explanation of how Table 7 can be used by practitioners and what practical benefits it has.

Table 7 Summary of findings Business model elements (author's own)

No	Dimension	Parameter	Characteristics, Features and Choices		*red entries: surprising finding
THEME 1: INVESTMENT FINANCE GOVERNANCE					
1	**Governance**	Joint Venture Sole Owner	Customer Customer	Investors (banks, investment funds) Plant builder	Government / state-owned SPV – special purpose vehicle
		Government	Regulations	Barriers	Drivers
		Assets	H_2 Pipelines	H_2 Grid	Electrolysers
		Value chain integration*	Highly integrated – other members of the value chain exert governance	Not integrated – no governance from other value chain members	
2	**Invest & Finance**	Investment risk Financing	Hedging mechanisms Corporate financing (on-balance solution)	Regulatory rules Project financing	Taxonomy guidelines for investors Municipal financing
		CAPEX	Bank loan, investors (e.g. funds)	Equity capital of owners	CAPEX funding source (e.g. IPCEI)
		OPEX	Double auction (e.g. H_2 Global, Hydrogen Bank)	CfD – Contracts for Difference	OPEX funding source (e.g. IRA)
		Preferred business setups	H_2 clusters	Onsite production	
3	**TIME**	Duration for Financing			
		Duration for approvals			
THEME 2: ACTORS & MARKETS					
4	**Markets**	Customers industry	Steel	Refinery	Chemicals, Cement, other
		Customer sectors	Mobility	Heat	Private households
		Region	Germany	Europe	worldwide
		Market size 2030 for green H_2 Market price	Europe: 20mill tonnes H_2 per year Not existing mechanisms (double-sided auction) under implementation	Germany: 3mill tonnes H_2 per year (12 billion € estimate) Price estimate competitive price 3,5-4€/kg	Price estimation wish from industries using grey H_2 today 1.5 – 2 €/kg
		Buying motivation green H_2	Regulatory: RED II, RED III, GEG, and other	Price - green H_2 lower than other H_2	Other
5	**Actor roles** one actor can have multiple and interchangeable roles in a project to project	Customer	H_2 off-taker	Other products off-taker	
		Provider of H_2, H_2 Derivatives, H_2 transport/logistics	Plant operator – large incumbent Energy Company	Logistics operator – large Incumbent Oil & Gas company	Medium-sized, new actor (start-up)
		Supplier – equipment, services, consumables	Technology providers	Component suppliers	Commodities (electricity etc.)
		Partner	Role clear	Role unclear	
		Investor	Funds, family offices	Own equity provider	Banks, loans

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No	Dimension	Parameter	Characteristics, Features and Choices		
THEME 3: TECHNOLOGY & INFRASTRUCTURE					
6	**Maturity of products and technologies**	TRL (Technology Readiness Level)	Mature, available off-the-shelf	TRL 8 or 9	TRL <8
		Risk	Unexpected cost increases	Unexpected low lifetimes	Reliability of products & technologies
		Time	Learning curve domestic	Rising competition from outside the EU	Time to Market too long
		Manufacturing & Supply	Manufacturing capacities too low	Delivery times too long	No stable supply chain
		Supply chain	Stable and continuous	Not stable and continuous	Not existing
THEME 4: VALUE					
7	**Value creation**	H_2 sale	Green H_2 to reduce CO_2 emissions	Green by-products such as heat, oxygen	In case of domestic production: H_2 security of supply
		H_2 transport	In the gas grid via entry-exit system, i.e. grid fees	Transport of derivatives or H_2 carriers via €/kg transported or per kWh transported	Building pipeline/grid connection point
		H_2 Storage Flexibility for electrical grid H_2 clusters, business ecosystems	In caverns Day and intraday trading sharing of resources	In other storage Reserve energy Set up a kind of circular economy for some media/equipment	
		H_2 Derivates	Ammonia as raw material or transport means	Methane, methanol as raw material or transport means	
		Heat from H_2 burning.	In gas turbine	In heat supply applications	
		CO_2 savings	ETS	Other quota trading	
8	**Value proposition**	All-inclusive solutions	Value chain integrated offers, e.g. also, EPC and operation and maintenance for HRS		
		Security of H_2 supply	Own onsite production	Transport/logistics of H_2	Fixed supply and off-take contract
9	**Value capture, pricing**	H_2 price per kg	Oriented at the price of grey H_2	Price building via negotiation of supply and demand does not seem to be possible.	
		Double-sided auctions Single sided auctions	H_2 Global Contracts for difference	European Hydrogen Bank	
10	**Value configuration**	Procurement	Turnkey	Semi-integrated	Component
		Depth of knowledge	Build up your own resources	Enhance knowledge via partner network	

6.4. Findings: Interacting Mechanisms, Influencing Factors

Chapter 6.3 identified the business model elements currently influencing business models in the hydrogen economy. This chapter focuses on analysing factors and mechanisms that can potentially influence business model design, aiming to create a better understanding of the overall system of business models in the H_2 economy. The following sections present the factors and their potential impacts as analysed from the data aiming to extract information on questions like “How are the elements interacting?”, “Why are the elements interacting?” “What makes them interact?”. Relationship, origin, and impact found with sufficient evidence during the thematic analysis was noted. The analysis follows a system thinking approach, attempting to categorise causalities based on stratified ontologies (Bhaskar et al., 2017; Mingers, 2014). Table 8 in Section 6.4.4 shows the overall result Sections 6.4.1 and 6.4.2 and 6.4.3 provide narratives synthesising the findings in the data and some significant quotes that support the narratives.

In addition to the datasets coded in NVIVO, the survey results were also used as data sources. Data in the survey about barriers, drivers, and context topics were collected from about 30 participants; this significantly broadened the database for this research question and has been used to fine-tune and further ground the findings in the data. The explanations focus on the mode of action and impact and are generally kept shorter than in Chapter 6.3 to avoid repetition as far as possible.

Three themes - POLICIES & REGULATORY, OBSTRUCTIONS, and MOTIVATORS - were formulated during thematic analysis in NVIVO to inform this research question, with POLICIES & REGULATORY being the most important theme. It is also noteworthy that the frequency of coding for OBSTRUCTIONS and MOTIVATORS is balanced, indicating a similar amount of information on factors hindering and driving the H_2 economy.

6.4.1. Theme 5: POLICIES & REGULATORY

It seems common ground that policies and regulations are the biggest external factor influencing the ramp-up of the hydrogen economy (e.g. McKinsey, 2021; Schlund, Schulte, & Sprenger, 2022; TRANS4REAL, 2023). A sense of urgency has arrived in EU politics, science, and business, and favourable framework conditions must be created for the hydrogen ramp-up to prevent the industry from migrating away from Germany and Europe. I16 phrases this as follows:

> *Then it's like other great technologies that have been developed in our country, where we have invested much money, where unfortunately they are suddenly being built in America or Japan, and then that's it, then the economic investment is also gone.* (I16)

Subsidies for investments, e.g. funding for electrolysers and other related equipment and, in particular, funding for setting up the hydrogen grid, are demanded by the participants, representing the general opinion. See the following quote from I2:

> *But what we have here as a special feature is that there are still no possibilities to cover the costs via the existing customers because there are simply hardly any customers yet, and you would simply have to subsidise the expansion of hydrogen in the same way as you used to do with the natural gas network, so we need the state for that, so if it wants the hydrogen network, then it also has to co-finance it*. (I2)

Besides CAPEX, i.e. state aid for investments, the participants also emphasise the need to subsidise operating costs; instruments like the German “Industriestrompreis” (subsidised electricity prices for energy-intensive industries) are considered good. Several other instruments have been launched, introduced in Section 2.4.4, aimed at decoupling H_2 suppliers and H_2 customers and compensating for the initial price differences. These are, for example, the European Hydrogen Bank, H_2 Global, and Contracts for Difference. All are designed to bridge price gaps between the initial H_2 production costs and the willingness to pay on the customer side. The participants assess all those instruments as helpful but also as *“a bit cloudy”* (I14), confusing, too complex, and over-bureaucratic. Comparisons are drawn to Germany's former EEG. This German law was effective in building up renewable industries in wind and solar during the 90s (BMWK, 2023a) or mechanisms of today in the US, the IRA (inflation reduction act, see Section 2.4.4). I16 states:

> *And there is, of course, the fact that the model in the USA is smart, simple and much more efficient from a business perspective, so it's more interesting from a business perspective, let's call it that.* (I16)

One drawback Germany and Europe is facing is the absence of clear certification guidelines for green hydrogen. At present, there is a lack of clarity regarding the process of acquiring green H_2 certificates and identifying suitable applications for green hydrogen. There are divergent opinions on the pathways for transformation: some advocate for technological flexibility, even considering the interim use of blue or turquoise H_2 (for definitions, refer to Section 1.5), while others emphasise starting directly with green hydrogen. Many stakeholders argue that the current European definition of green hydrogen is overly restrictive and advocate for broader technological flexibility and exploration of alternative transformation pathways (refer to C5 for more details):

> *But in the transition period, before we have pure green hydrogen everywhere, we will probably have to accept different colours. So that everything is complete until 2040 or 2045. That's not going to happen.* (C5)

The EU has progressively raised the targets for emission reductions; the initiatives are the Green Deal (2019), the Fit for 55 (2021), and the RePowerEU (2022) program, which are introduced in Section 2.4.4. These EU legislations, translated into national law, are seen as overarching structures that direct the ramp-up of the H_2 economy.

The participants acknowledge that shaping the ramp-up for the H_2 economy is complex; as I12 notes, *"decarbonising complex industrial sectors entails transforming entire value chains"*. However, the participants do not wish for the German government to play a stronger role than it currently does. The majority of the participants see the role of the state in ensuring fair access to the hydrogen grid and technological openness, as well as in providing a favourable regulatory framework that enables market design and large-scale projects that bear higher investment risks. I9 summarises this as follows: *"The state can provide subsidies, particularly in areas that appear to be associated with greater risks from a business perspective, but which are nevertheless essential for decarbonisation to make progress in these sectors".*

This account provides the narrative about the main issues raised by the participants on the theme of policies and regulations. Much of the specific information contained in the data could not be included in the main narrative, due to scope restrictions, but is included in the summary table in Section 6.4.4.

6.4.2. Theme 6: OBSTRUCTIONS

In summary, the hydrogen economy ramp-up is hindered by several factors, including unclear or even adverse regulatory and political framework (see 6.4.1), insufficient funding, unfavourable market design, cost and time related issues and overwhelming bureaucracy. This is underpinned by the results of the thematic analysis, presented below and also supported by the survey results presented in Chapter 5.4.

The timely and detailed translation of the EU laws (see Section 6.4.1) into German law, such as the RED II (renewable energy directive, see Section 2.4.4 for introduction), but also the CO_2 emission quota and the regulatory for the gas grid are crucial. I13 emphasises that RED II and III are a *"very important basis, and as long as this is not in place, much of it is actually in a vacuum"*. I13 goes on that the same applies to the European hydrogen gas regulatory that is the enabler for building the gas grid in Europe (EHB, 2023). According to the EU, the deadline for adopting the gas package into national law was set on Jan 1, 2024. But the actors expect a further delay in adopting the gas regulation because the finer points have not yet been fully discussed at the EU level, and assume that *"no IPCEI funding will be spent until then"*, I2.

Addressing funding rates is critical for the success of projects. The current challenge lies in the lengthy and cumbersome approval processes, which drive up project costs and diminish proportional funding rates due to capped total funding amounts. Consequently, the likelihood of project realisation decreases while project risks escalate. Numerous quotes substantiate this viewpoint; a selection is provided below:

> *"so far, the subsidy or incentive mechanisms are not yet sufficient to make the whole thing economically viable".* (I8)

> *“Europe Fast", Europe must become fast, then there will be investments, including non-European investments”*. (I15)
>
> *“We need a bureaucracy reduction act to cut the red tape here in Europe”.* (C9)
>
> *“We have a system in Europe, but we should streamline it and make it light, deregulate and try to accelerate, broaden the technology scope, speed up all the licensing procedures that are still the bottleneck in this process that we have, that we are facing now”.* (C7)

The lack of a market design that enables companies to decide on investments also poses a problem. The participants are unanimous in their opinion, saying if politicians fail to create a market design, it could lead to further delays in the ramp-up of the hydrogen economy. Market design encompasses supply and demand, including the complete value chain. The causal relationship and interaction are complex; this was explained by several project actors, e.g.:

> *“And when you have a project, the issue at least that you have to combine or you have to make sure that all these different parts fit together. And that is the issue. You have to find a customer at the end of the day with a carbon contract for a difference that matches your value chain. You have to find support for your electrolyser. You have to find a supplier for electricity. So that is not that easy, and that is a coordination problem*”. (C9)

Cost-related issues also pose significant challenges. Large projects require substantial investments and high operating costs. The economic viability of switching to hydrogen is threatened by its expensive production through electrolysis and the costly conversion of existing processes and plants to hydrogen-capable ones. A panellist of C7 sets out, *“For us, it’s all about costs”*. He continues by explaining customers’ willingness to pay for green copper, i.e. copper that is produced using green H_2: *"…they all want to have green copper. They are all not willing to pay 1ct more per tonne for green copper"* (C7).

Recent interest rate rises, general price increases, and higher inflation rates exacerbate the investment risk. The creditworthiness of those who built a hydrogen generation plant and the customers for the hydrogen plays an important role in the financing of projects. C3 explains, "If *the customer drops out after three years, then eventually there may be no one who will buy this hydrogen from us for the remaining time at the same price"*. Launching projects when the entire value chain is not covered by functioning business models is seen as a high entrepreneurial risk.

6.4.3. Theme 7: MOTIVATORS

Expanding upon the preceding chapter, it becomes evident that fostering conditions contrary to those inhibiting market growth would effectively propel it forward. This assertion finds support in both the thematic analysis of this subject and the findings from the survey (refer to Section 5.4). Principally, establishing a transparent and supportive regulatory framework emerges as a crucial factor in stimulating demand for green hydrogen and fostering the growth of its market. Furthermore, respondents express a need for expedited and streamlined funding mechanisms that are tailored and enticing. There is a notable desire for an alternative subsidy approach aimed at operational costs, with examples such as the IRA in the USA and the former EEG in Germany (details provided in Sections 6.4.2 and Section 2.4.4) being cited as favourable models.

The participants call for the government to take action to ensure an "*investment-secured market*" (I16). I16 also reminds the German government of its goal, stated in the governmental coalition contract, of becoming the global market leader in hydrogen technologies, stating, *“then there will also be a political mandate to fulfil this agreement in terms of [market] design. This will then also become an entrepreneurial mandate”* (I16).

In particular, the project actors classify the EU legislations, the derived policies like RED II and RED III and various quota obligations for introducing green hydrogen to decarbonise industrial sectors (see Section 2.4.4) as the underlying driver that prepare the ground for creating the hydrogen demand in the various industries. The capability of transporting hydrogen in large quantities is also seen as inseparably linked to hydrogen demand. One will not be possible without the other; the following selection of quotes supports this claim:

> *“…but in addition to funding for the infrastructure and individual projects, they need an overall setting of framework conditions so that there is a general demand for hydrogen in the first place”* (I3)
>
> *“…the Renewable Energy Directive stipulates that there should be a quota for green hydrogen in industry, which could then indirectly, so to speak, create a willingness to pay” […..] “so for refineries or something like that, that there is a willingness to pay. Yes, they also have a quota obligation”* (I14)
>
> *“Chancellor Scholz is meeting with the managing director of the TSOs to express his expectation on really making this happen. If this works, it will give an obligation for the TSOs (i.e. transmission gas grid operators) to build this* H_2 *core grid”* (C8)

Political actions are pivotal in driving climate solutions forward, serving as significant catalysts in pursuing sustainability. Quotas, for instance, can effectively raise the cost of CO_2-heavy products or even restrict businesses unless they transition to decarbonised processes. These quota mandates not only incentivise the adoption of greener practices but also foster a burgeoning demand for green hydrogen, prompting a willingness among consumers to invest in sustainable alternatives. While political initiatives and their implementation are key drivers shaping the macroeconomic landscape of the hydrogen economy, it is crucial to acknowledge the presence of additional external factors that could gain prominence in the future. These external influences warrant attention, as they have the potential to significantly impact the trajectory of sustainable development.

Recent events, like the Russian war, the energy crisis, and the potential shortage of fossil energy in the EU and Germany, have increased the urgency to act more quickly and strive for more independence and security in the energy supply. The participants see various drivers for the ramp-up arising from these external circumstances. The EU strives for independence in the energy supply; hydrogen allows it to diversify and be used not only as a molecule for industrial processes but also as a substitute for natural gas, e.g., for heating and electricity generation by hydrogen-fuelled gas power plants. I3 explains the relations for Germany, in particular for the heating and electricity sector about the German decision to phase out coal as a primary energy source in the near future:

> *"The coal phase-out is coming far too quickly to be able to make it electricity-based, so to speak, because they [i.e. the government] can't manage electricity-based because they don't have the storage facilities, so they can't manage this enormous load change between summer and winter in the electricity system"* (I3)

Some participants stressed the importance of independence from energy imports as a significant driver. They suggest that, despite the potentially higher cost of producing hydrogen in Germany than importing it, establishing domestic production facilities for green hydrogen is advisable for independence and supply security reasons. I4, representing the views of other participants, supports this stance:

> *“Let's say the hydrogen comes from Saudi Arabia or wherever for €2.00 a kilogramme, then we can say great; we don't need to start with €5.00 here. We'll just buy it for €2. That would probably be a fatal decision because then we would go from one dependency to the next, and we should avoid that, so in this respect, it is also valuable to expand, develop and expand production capacity in our own country”* (I4)

In summary, diversification is a major driving force. This encompasses a broad spectrum of initiatives, ranging from diversifying the technologies employed for generating fossil-free energy to the vital task of decarbonising industries and revolutionising transportation methods and routes for transport. Moreover, it extends to diversifying the sources from which hydrogen is imported, ensuring resilience and sustainability. C1 encapsulates the critical importance of breaking free from dependency chains that hinder the journey towards a cleaner, more sustainable future:

> *“If other countries around the world have the opportunity to prevent our transformation phase, for example, because they have a monopoly on input factors, then they can throw a spanner in the works and trigger social conflicts*” (C1)

The last driver for the ramp-up of H_2 business to be introduced in this synthesised narrative is that of “having enough renewable energy”. “Having enough renewable energy”, e.g. onshore or offshore wind, is potentially a strong driver because the electricity then tends to be cheap, leading to cheap H_2 production costs. As I5 sets out:

> *"in [German city]* (removed due to confidentiality*), where there is so much construction going on, that's where all the offshore parks are actually just arriving, so there will possibly be one or two direct connections".* (I5)

The deciding question is whether electrical grid expansion is more difficult and expensive than local H_2 production.

Although this topic was only mentioned by one participant, it is considered significant. It could be a strong driver and be currently overlooked by many players because it requires thinking across several steps of the value chain. The Chapter 7 takes up this topic in the discussion.

6.4.4. Summary Findings for Interacting Mechanisms, Influencing Factors

The previous three sections presented the synthesised narratives for the themes, which provide insight into interacting mechanisms and influencing factors. The field data contains more detailed information than what was presented in the syntheses, so in addition to Table 8 a detailed summary in table format has been compiled and is available in Appendix 6 This detailed summary can be useful for practitioners who want an overview of the current influences.

Table 8 provides an overview of the influencing factors and their associated impacts. This representation offers a simplified depiction of a portion of the causal chain involved. Within the data, various factors have been identified and categorised primarily as prerequisites, preconditions, or inputs for potential business models, denoted as "Variables/Factors Input" in the table. Additionally, factors are extracted as outputs, resulting from the designs of business models that process these input variables, along with other processes not explored in this study, marked under "Variables/Factors Output." The "Indicators and Impact" column elucidates the effects and influences these variables can exert, thus occupying a central position in Table 8. To enhance readability, alternating shades have been applied to the rows. Notably, variable names crucial for subsequent model development are highlighted in bold for easy reference in the following sections.

Table 8 Summary of findings influencing factors and interacting mechanisms (author's own)

Variables / Factors Input	Indicators and Impact	Variables / Factors Output
1 Market design, e.g.: • **CO_2** pricing, CCfDs etc.	• increases value of green H_2; creates a market for H_2 by incentivising industries for decarbonisation; creates demand for H_2; facilitates coordination of supply and demand • if favourable, then risk for projects and investment is reduced	**9 Demand** H_2 **10 Price** H_2 **11 Risk** **12 Degrees of a liquid market (including infrastructure)**
2 CO_2 pricing	• increases price for the use of fossil energies and therefore makes green H_2 more attractive; improves the economics of the business model	Price H_2
3 Quota obligations, e.g.: • RED II, RED III • Aviation-fuel directive	• creates market and demand for H_2, however indirectly (i.e. after translating it to national laws) • raises value (i.e. willingness to pay) for green H_2	Demand H_2 Price H_2 Degree of a liquid market
4 CAPEX funds, i.e. any investment subsidies, e.g.: • IPCEI, Reallabore etc.	• improves economics of business model; reduces levelized costs of H_2 ($LCOH_2$) produced; raises appetite for investment	**13 Economics of business** **14 Cost** H_2 **15 Amounts of investments** Risk
5 OPEX funds, i.e. any operating cost subsidies, e.g.: • subsidised electricity prices, production tax credits • **H_2** Global	• improves economics of business model; reduces levelized costs of H_2 ($LCOH_2$) produced; • raises appetite for investments	Economics of business Cost H_2 Amounts of investments Risk
6 Macroeconomics, influencing H_2 cost, e.g.: Inflation rate, electricity price	• influences the levelized costs for H_2 produced and the economics of the business model; • influences EU /Germany's position in global competition, threats industry to migrate	Economics of business Cost H_2, Risk **16 Threat of de-industrialization**
7 EU dependency on energy imports	• increases willingness to invest in domestic H_2 production; • increases openness for H_2 generation paths; increases openness for H_2 import paths; • increases urgency to act and to lower administrative burdens	Amounts of investments **17 Timeline** **18 Security of H_2 supply**
8 Processes and **administration burdens**	• influences risk and timeline for projects • prolonged timelines influence project costs; • overall, it influences the EU /Germany's position in global competition and is a threat to the migration of industry	Timeline, Risk Economics of business Threat of de-industrialization

Summarising the results for this research question (RQ2), that is - to find out about how those elements are interacting - there are two main findings:

(1) Policies & Regulatory issues have the most influence on how the elements interact with each other. These issues currently set the framework for interaction possibilities.

(2) Several factors and their impact (see Table 8) were outlined that either drive or hamper the ramp-up of the H_2 economy. The factors can be categorised according to their tendency as input or output factors.

Table 3 in the literature review (Section 2.5) provides information from literature and a basic framework, the CIMO (context, intervention, mechanism, outcome) - model of Denyer et al. (2008) for analysing the interacting mechanisms and influencing factors being present in the H_2 economy. Although Table 8 does not use the terminology of the CIMO anymore, the underlying understanding is still similar to the CIMO logic. The “Variables / Factors Input” column (column 1, Table 8) corresponds to the context (C) and the intervention (I) parameter of CIMO, the “Indicators and Impact” column (column 2, Table 8) corresponds to the mechanism (M) parameter and the “Variables / Factors Output” (column 3, Table 8) corresponds to the outcome (O) parameter of CIMO.

The decision to abandon the CIMO terminology and instead use a terminology that facilitates the representation of business model design activities as a process seemed more appropriate for the development of the conceptual meta models developed for the H_2 economy as presented in Section 7.5 and Section 8.3.2.2.

6.5. Findings: Considered business models today

The following sections present the themes developed from the codes and data to inform the research question, "What business model designs are considered today for upcoming large-scale green hydrogen projects?" Three themes have been formulated that inform this research question; these are "BM 2030", "BM CAUSALITY", and "BM TODAY". Twenty-nine files and 161 references have been coded for the three themes. In contrast to the two other questions on business model elements (6.3) and interacting mechanisms (6.4), where the results have been summarised in tables, the summary for this question is presented as a narrative. The results inform two aspects: firstly, an outlook on the business situation in 2030 is provided, and secondly, an early business model design is outlined.

Participants were asked to share their vision of the hydrogen economy in 2030. The responses varied; some expressed optimism about the business opportunities in 2030, while others were more cautious. The selected quotes represent the diverse opinions expressed by the participants:

> *"I don't expect anyone to earn any real money with large-scale production until 2030. […]."* (I13).
>
> *"so we will see 10 GW of electrolysis in Germany in 2030".* (I15)
>
> *"I think that in any case, there will probably be large electrolysis plants in the north and then infrastructure down south"* (I8)
>
> *"We need the off-takers, we need the generation, we need the determinants to import. And this leads us to the typical chicken and egg problem we must overcome. And the question is, how do we overcome this? On PowerPoint, it is easy, in practical terms, it's a bit more challenging, especially when it comes to significant money, you have to invest"* (C8)

Analysing the two themes “BM CAUSALITES” and “BM TODAY” results in an outline of an early business model design, which is informed by the explanations of several participants. Furthermore, it is already about to be implemented as one of the project actors reports.

Such early business model designs are called “H_2 Cluster” or “Local H_2 Hub,” and according to the participants, a number of preconditions must be in place to establish a viable “H_2 Cluster” business model.

Supported by several quotes such as:

> I8: *“if you have a good location for a renewable energy plant and then you install a smaller electrolyser yourself, perhaps some industrial companies could also do this.”*
>
> C2: *“In other words, we will need these local island grids, local hydrogen production processes.”*
>
> I3 states that *“local hubs can also emerge, where relatively small applications, such as automotive applications such as logistics, paint shops, etc., have demand and willingness to pay and are located closely together.”*
>
> I3 continues: *“Of course, these are not huge quantities of hydrogen utilised, but they are locally close together. In this respect, it's also not that much of an effort.”*

An ideal “H_2 Cluster” business model can be sketched. It would involve creating a local hydrogen business ecosystem that includes local proximity of H_2 generation and H_2 consumption, and renewable electricity generation. It would co-use and share as many products and auxiliaries as possible, and the issue of hydrogen transport would be solved by a direct pipe built between the H_2 producer and the H_2 consumer, which is possible thanks to the proximity. There would also be a direct contract between the hydrogen producer and the hydrogen customers, and this would overcome the supply and demand problem of the chicken and egg.

Local hubs or hydrogen clusters are predestined to become pioneering operational projects shortly. For instance, erect an electrolyser adjacent to a refinery, facilitating the seamless transportation of hydrogen through direct pipelines. Moreover, harnessing excess heat for district heating and implementing water recycling further exemplifies the multifaceted benefits of such initiatives. Furthermore, these ventures hold the potential to generate additional income through the trading of reserve energy, helping their economic viability and sustainability.

Summarising the results for this research question, that is - what business model designs are considered today for upcoming large-scale green hydrogen projects - there are two main findings:

(1) The actors do not have a uniform opinion about what business model designs will look like in 2030, and they are unsure whether the business models will be profitable or not.

(2) The participants seem to agree that “H_2 Clusters” (synonymous for “H_2 Hubs,” “Local Hubs,” and “H_2 business ecosystem”) are most likely the first viable business model designs.

6.6. Concluding the chapter: Thematic map and wrap-up

The thematic analysis of the comprehensive datasets has revealed ten discernible themes that shed light on the exploration of the three core research questions. Themes 1 through 4 correspond to the first research question, centred on identifying the prevailing business model elements perceived by the participants. Moving forward, themes 5 to 7 delve into the intricacies surrounding the interactions and influencing factors among these identified elements, addressing the second research question. Lastly, themes 8 to 10 are instrumental in addressing the third research question, which delves into the existing landscape of business model designs. For further insight and reference, the complete codebook, extracted from NVIVO, showcasing all codes, file counts, and code counts, has been included in Appendix 4. In total, this analysis has yielded four succinct summary findings, comprehensively detailed at the end of this section, providing a comprehensive overview of the research outcomes.

Only the interplay of the themes, the cross-analysis, and how they are related offers the full picture and gives the full information the thematic analysis can provide. A thematic map (Braun & Clarke, 2006; Byrne, 2022) is a graphical means to collate how the themes come together, and depict the relations between the elements. A thematic map should inform the overall research question (Byrne, 2022), which is to investigate what business logic enables business models for large-scale green hydrogen projects. The NVIVO concept map tool has been used to produce the thematic map shown Figure 34. From the top to the bottom Figure 34 shows the main node "BUSINESS MODEL ELEMENTS" with its collated themes 1 to 4 (green rectangular shape), which is related to Finding #1 and the main node "INTERACTING MECHANISMS, INFLUENCING FACTORS" with its collated themes 5 to 7 and its relation to Finding #2. These two nodes are linked, with a bidirectional arrow showing mutual influence. But more than that, the interaction between the two nodes can create conditions that may or may not allow business models to emerge; this is explained in the orange elliptical shape, labelled as Finding #3. The further way down to the bottom of the graphic is relatively straightforward. The theme "BM CAUSALITIES" is collated to the main node "BUSINESS MODEL DESIGNS", which then splits up to the themes "BM

2030" and "BM INTERIM", which are not linked to each other, as theme 8 describes potential future business models as predicted by the participants for the year 2030 and beyond and theme 10, describes business models that can be observed already.

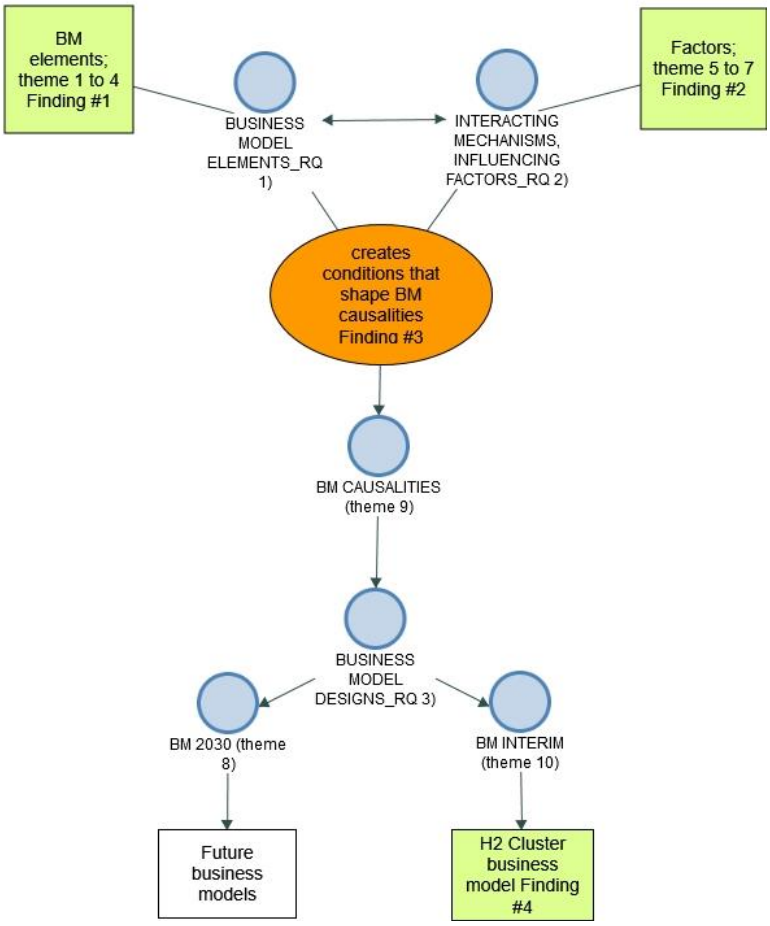


Figure 34 Thematic map showing the main nodes, themes and their interlinking (author's own)

This thematic map was further developed into a conceptual framework by grounding it to the appropriate academic concepts; this is presented in Chapter 7.

Attempts were made to analyse the interaction between the business elements and the factors in more detail (see orange elliptical shape Figure 34). In one attempt, the factors and the business model elements were regarded as variables, and it was tried to find out about their mutual dependency by asking questions like "If A changes, is B also changing?” A drafted variable-by-variable matrix (Miles et al., 2014) did not produce meaningful results. Why this might be the case is discussed in Section 7.4.

Four findings and their related results answer the central research question: "What business logic enables viable business models for large-scale green H_2 projects?

Finding #1: Ten business model elements and numerous available choices (see Table 7) for their detailed design have been found, potentially building the business models. Some of those elements are surprising, and they are further discussed in the discussion chapter (Section 7.2).

Finding #2: A number of factors, also called variables, have been found to influence and frame potential business models (see Table 8). The identified factors are predominantly external.

Finding #3: Multiple connections, influences and inter-dependencies exist between the individual elements, factors and business model elements (see Figure 34). A detailed analysis of which element is connected to which and how, was attempted but did not lead to a meaningful result. This aspect is further discussed in the discussion chapter (Section 7.4).

Finding #4: Only feasible business models can emerge within the currently given causalities. As of today, these are only “H_2 Cluster” business models (see narrative in Section 6.5).

The interpretation of the impression from the interviews and the conference contributions can be summarised as follows:

- There is significant activity in various areas, with numerous drafts, consultations, and initiatives being discussed regarding the establishment of a regulatory framework and the development of a hydrogen infrastructure.

- However, the project actors seem disconnected, as it is very difficult to gain an overview of the policies and restrictions that apply to individual hydrogen projects at given times.
- This creates a gap between what is theoretically available and underway, and what the actors have at their disposal to act in practice.
- The need to ensure value chain-integrated business models, which consider all steps, from green electricity sourcing to the usage of green hydrogen, is perceived by project actors as a complex and difficult burden when conducting hydrogen business

7. Discussion and re-integration of the findings into the literature

7.1. Introduction to the chapter

This chapter discusses the findings and reflects the findings with the literature review (Chapter 2) and the philosophical approaches (Chapter 3). Special emphasis was placed on the discussion of surprising findings and their interpretation.

The attempt to generalize the specific results is made by mapping them into scholarly concepts. The specific results are abstracted and conceptualised as far as it seems reasonable. Graphical presentations support the argumentation in this chapter, diagrams present the new conceptual frameworks that have been developed through the discussions.

The discussion chapter is structured in five sections and concludes with a summary section.

Section 7.2 aligns the insights gleaned during fieldwork with the academic perspectives on business models outlined in the literature review (Section 2.4). Section 7.3 compares the findings from the literature review with those obtained from the fieldwork, with a particular emphasis on uncovering unexpected discoveries and endeavouring to provide insightful explanations. Section 7.4 delves into the methodology for investigating causal relationships and introduces advanced concepts from system theory to better navigate the complexities identified within this research. Section 7.5, develops novel conceptual frameworks by leveraging the study's findings while anchoring them firmly in established academic concepts. Finally, Section 8.6 elucidates the extent to which generalizations can be drawn from the conclusions drawn within this study, providing a comprehensive perspective on the broader implications of the findings.

The summary section of the discussion chapter concludes by critically reassessing the extent to which the research questions have been answered. The summary section transits to the contribution chapter (Chapter 8) by summarising the answers to the research questions.

7.2. Allocating the results in the literature

The business models for the H_2 economy are less developed, than initially expected by the author, which was a major finding of the screening phase (phase 1) (see Section 5.5). As a result, the research became less predictable and prescriptive. Surprisingly, the situation found during fieldwork, described in Chapter 5 and Chapter 6, largely corresponds to the accounts given in the literature review (Sections 2.4, 2.5, and 2.6). This statement is further broken down from general to detailed perspectives.

This study can be assigned to both business model research and business model innovation research, although this kind of vagueness is criticised by some authors in this academic field (see Chapter 2.4), however, for this study this is a consequence of the exploratory nature of the study.

Chapter 2.4 has introduced the state of the art, current trends and gaps of business model research and business model innovation research. In addition to digitalisation, e-commerce, servitisation and others, there is a trend towards developing sustainable business models that consider ecological, societal and environmental factors. According to the literature review (Chapter 2.4) these circular and sustainable business models were considered relevant for this research. However, the results do not directly confirm this, as none of the participants explicitly mentioned sustainability or circularity. While the H_2 economy is established because of environmental reasoning, the data analysis shows that economic reasons are decisive for entering into the green H_2 business rather than motivation for a more sustainable business model. This is underlined by the quote of C7 (see Section 6.4.2) *“they all want to have green copper. They are all not willing to pay 1ct more per tonne of copper”* (C7).

A thoughtful contemplation of the literature review positions the study findings within the broader theoretical framework. Chapter 2.4 advances the perspective of considering business models as purposeful and dynamic activity systems to generate stakeholder value (Zott & Amit, 2010). Within this paradigm, actors – companies - have the autonomy to shape their strategies and mould their businesses according to their resources and expertise, thereby making strategic decisions tailored to their objectives (Casadesus-Masanell & Ricart, 2010). This entails crafting various elements of their business model, including the revenue model, value proposition, and distribution channels (Osterwalder et al., 2005; Wirtz et al., 2016), all of which collectively contribute to the overall functioning and success of the enterprise.

It seems appropriate to adopt this dynamic activity system perspective with choices and consequences to a large degree. The field of the study is highly active, with governmental guidelines being frequently launched, changed, and put into action or withdrawn (see Section 2.4.3). The study’s results show a large number of theoretically available choices (Table 7, Table 8), that could be arranged in an appropriate way to compose a company’s business logic (Osterwalder et al., 2005).

The fieldwork and the findings clearly show that macroeconomics are the prevailing influences that currently impact the business models for the H_2 economy. Moreover, the findings (Table 8) show that the macro-level influences take place on several levels and are interlinked, e.g. at the EU level and the national government level. These features of layers of complexity and external interlinkages are not broadly covered in literature, as explained in Section 2.4. Only a few authors from the business model domain offer concepts for the macro-level view (Foss & Saebi, 2017; Jocevski et al., 2020; Osterwalder et al., 2005), these are used for developing the revised conceptual framework.

For the sake of completeness, it should also be said that many scholars in business model research have focused on the micro-level view, i.e. adopting a company perspective with a strong focus on the company resources and competencies and organisational structures, e.g. Demil and Lecocq (2010), but also Zott and Amit (2010) and Foss and Saebi (2017), at least in parts of their work. As there were surprisingly no findings on the micro-level view in this study, the academic concepts related to the resource-based view or other company-focused perspectives are, therefore, not relevant to this study.

In summary, the study's results align with the business model literature. The concept of business models as dynamic activity systems (Zott & Amit, 2010) being composed of a set of building blocks (Osterwalder et al., 2005) that act together purposefully to produce something meaningful is confirmed. The approach to business model design as a selection from available choices (Casadesus-Masanell & Ricart, 2010), allowing actors to choose the most suitable set for specific conditions to develop a viable business model (Baden-Fuller & Morgan, 2010) is also supported.

The study's insights into the impacts of macro-environmental factors and the intricate interplay among various systems and levels are only partly corroborated by existing literature (Jocevski et al., 2020; Wirtz & Daiser, 2017). This is primarily due to the limited availability of literature addressing these subjects.

The next section provides a detailed discussion of the individual findings and how they relate to literature and the initial conceptual framework.

7.3. Comparing and contrasting the results with the literature

This section compares and contrasts the study's findings with the synthesised results from the literature review and compares them with existing frameworks from the literature.

The research questions that guided the literature review (Chapter 2.5) are nearly identical to those that guided the data analysis (Chapter 6), that makes it easy to compare the results.

The first research question that guided the literature review was:

(1) What elements, drivers and parameters are potentially going to play a role in future business models for building large-scale green hydrogen projects?

The first question that guided the analysis of the coded data and the development of the themes was:

RQ 1) What elements are the (future) business models consisting of?

The synthesis from the literature review are documented in Chapter 2.5, Table 2, the results from the data analysis are documented in Chapter 6, Table 7.

<u>Comparison of business model elements</u>

The following table compares the results of the study (Table 7) with the synthesis of the literature research (Table 2) and with the "components of the integrated business model" (Wirtz et al., 2016, p. 44). The Wirtz et al. (2016) "integrated business model" has been chosen for this comparison, because with its breakdown into nine partial models, it seems to be sufficiently comprehensive, as it covers many areas and it also covers the meta-level, such as strategic components.

Table 9 BM elements comparing and contrasting

BM elements – literature review (Table 2)	**BM elements – study results (Table 7)** *red entries: surprising findings	**Components of the integrated business model (Wirtz et al., 2016, p. 44)**
	1 Governance (legal and organisational structure)	**Strategy model** (Strategic positions, BM value proposition)
	2 Invest & Finance (CAPEX, OPEX, financiers)	**Financial model** (financing model, capital model, cost structure model
	3 Time (durations for finance and approvals)	
Key products & services (what products & services do we offer)	**4 Markets** (industries, customers, regions, market size, market price)	**Market offer model** (competitors, market structure, value offering/products and services)
Relationships (to customers) **Stakeholders** (know who is influencing the business)	**5 Actor roles** (supplier, customer, investor, also one actor can have changing roles)	**Customer model** (customer relationships, channel configuration)
Network models (also strategic networks, interconnected business models)	**6 Maturity of products and technologies** (TRL, risks, supply chain security, H_2 infrastructure)	**Network model** (BM networks, BM partners)

Value generation (value networks, how to generate value) **Value proposition** (what is the overall offer)	**7 Value creation** (H_2 sale, H_2 transport, heat sale etc.)	**Revenue model** (revenue streams, revenue differentiation)
Value dimensions (also ecological and societal networks)	**8 Value proposition** (also value chain integrated offers, e.g. including electricity supply, turnkey solutions)	**Procurement model** (resource acquisition, information)
	9 Value capture/pricing (price building via negotiation of supply and demand is not yet possible)	**Manufacturing model** (manufacturing, value generation)
Key knowledge (companies competencies)	**10 Value configuration** (depth of value generation, own knowledge)	**Resources model** (core competencies, core assets)

It is important to note that the study results presented in the centre column are organised in descending order of theme relevance. This means that the elements of "Governance," "Invest & Finance," and "Time" are ranked highest in relevance based on the number of file codes and reference codes. Interestingly, for the business model element "Time" (Element 3), no equivalent is found in the comparison models. While there may be debate surrounding whether “Time” qualifies as a business model element, it has been included in Table 7 due to its significant concern among participants regarding the timely settlement of financing and approvals. This inclusion stems from the understanding that failing to secure financing and approvals, even when all other conditions are met, can hinder the design of a viable business model. Notably, challenges related to financing and approvals aren't unique to hydrogen projects; other endeavours with substantial financing requirements and extensive approval processes, such as offshore wind park projects, face similar issues (Energien, 2023). Therefore, it is somewhat surprising that “time” as a business model element is absent from academic frameworks.

For the business model elements 4 and 5, i.e. “Markets” and “Actor roles”, there are equivalents in the synthesised literature (left column,

Table 9) as well as in the academic framework (right column, Table 9). The speciality found in the study, noted in red in the centre column of Table 9, is, that it has been reported by the participants that actor roles in hydrogen projects can be somewhat fuzzy and need not be clearly distinguished. This means for example, that one and the same actor can be both an H_2 customer and an H_2 supplier in a project. This is the case for instance, when the H_2 customer also holds shares on the H_2 generation plant. The hypothetical explanation, why actors are interested in such multiple roles that also complicate the business model designs, is that they have an interest to acquire knowledge. If one takes on different roles in the projects and act alternately as a plant operator, a customer and a supplier, then one can build up in-depth knowledge of the entire H_2 economy system.

The business model element 6 “Maturity of products and technologies” with all its features, such as technological readiness level, H_2 infrastructure, risk, time, supply chain is noted in red and has no direct equivalent in the other columns of Table 9. The other both columns speak about network models and relate to strategic networks and partnering. The main reason for this may lie in the immaturity of the entire hydrogen industry, with products and infrastructure still being in the development stage.

Typically, business model design is based on readily available, market-ready products that are also transportable and have existing distribution channels. However, this is not the case for the hydrogen industry. Participants emphasized many times that the lack of transport and storage infrastructure is a major obstacle for the business model. Since a similar element does not appear in the other frameworks of

Table 9, it can be assumed that it only plays a temporary role during the ramp-up phase and becomes obsolete as the hydrogen technology and infrastructure mature.

The business model elements 7 to 10 in Table 9 describe the theme "Value". Although they have equivalents in the literature synthesis as well as in the academic framework (left and right column, Table 9), they differ in detail. For example, the aspects of resources, core competencies, key knowledge play an important role in the literature synthesis and also in the Wirtz et al. (2016) framework, but the corresponding element "Value configuration" is only ranked in the 10^{th} place in the study results (Table 9). Actors tend to found new companies, joint ventures, special purpose vehicles etc. for the H_2 business. The idea might be that these new companies then could be equipped with the appropriate resources and competencies, so that there is no need to adapt to existing competences and resources as it is the case in existing companies that want to develop new business areas.

One noteworthy aspect lies in the specialization regarding element 8: the "Value Proposition." According to the study findings, it is evident that actors have yet to solidify their value propositions, opting instead to explore various alternatives. For instance, some are delving into value chain integrated offers. This entails an expansion of their offerings to encompass products and services from adjacent value chain steps. For example, operators of wind parks are venturing into providing green hydrogen production, while green hydrogen producers are extending their services to include transport and storage of hydrogen. This dynamic approach illustrates a willingness to adapt and innovate within the industry.

It can be concluded that it appears that many project players have not yet defined their final role, their offer, or their depth of added value and will test out different set-ups and roles for themselves in various projects.

Comparison of relationships and interactions and influencing factors

The second research question that guided the literature review was:

(2) What might be their relationships, interdependencies, and modes of action?

The second question that guided the analysis of the coded data and the development of the themes was:

RQ 2) How are those elements interacting?

The synthesis from the literature review are documented in Chapter 2.5, Table 3, the results from the data analysis are documented in Chapter 6, Table 8.

The comparison of the results of the study (Table 8) with the synthesis of the literature research (Table 3) is not as straightforward as for the business model elements in the previous section, as the entries in the tables are not directly comparable line-by-line. Furthermore, in contrast to the Wirtz et al. (2016) framework, which is well suited for evaluating the business model elements, no theoretical framework was identified that is sufficiently suitable for evaluating the relationships.

The CIMO – logic (Context, Intervention, Mechanism and Output) has been used to organise and present the literature synthesis (see also Section 2.5 and Table 3 for background information on CIMO and design science). The CIMO – logic is proposed by Denyer et al. (2008) to develop design propositions not only for the field of engineering and other fields of applied science, but also for the field of organisation and management. In brief, applying CIMO – logic can help to formulate design propositions that enable a deeper understanding of the situation being analysed and an understanding of the causal mechanisms; Section 2.5 provides more background information about the Design Science paradigm and the CIMO approach. The CIMO approach taken in Section 2.5 has proven to be effective to gain an initial overview of main variables, relationships and causal connections relevant to business model design for the H_2 economy.

Overall, the study results (Table 8 and more detailed Appendix 6) confirm the CIMO literature synthesis (Table 3). The context variables C1 to C4 and the intervention variables I1 to I4 identify the EU climate goals, EU and national policies and regulatory guidelines, such as quota obligations and CO2 emission prices, as variables of high relevance. The study results (left column in Table 8) list “Market design”, “CO_2 pricing”, “Quota obligations”, “CAPEX funds”, and “OPEX funds” as relevant variables and thus confirm the literature synthesis. In addition, the study results are more detailed than those of the literature synthesis and provide information on which programs (e.g. IPCEI, Reallabore) and which regulatory directives (e.g. RED II, RED III) are currently under discussion.

Following the CIMO logic, the literature synthesis also drafted some of the mechanisms triggered by the interventions and generated the outcomes. Table 3 lists six mechanisms (M1 to M6) and four desirable outcomes (O1 to O4), for example the profitability of projects, rising H_2 market demand and projects realisation. The mechanisms and the outcomes of the literature synthesis are rather superficial; the comparable study results are much more detailed. The study results list ten output variables (right column in Table 8), e.g. “Demand of H_2”, “Price H_2”, “Risk”, “Degree of a liquid market” etc. that are provoked or at least impacted by various causal linkages (centre column in Table 8). Explaining causality turned out to be the most difficult analysis task in this study, Section 7.4 is dedicated to the discussion of causality.

Upon juxtaposing the study's findings with the insights garnered from literature synthesis, notable distinctions emerge. Notably, factors associated with public acceptance (referenced in C5, I6, M6, and O5 of Table 3) do not manifest within the study results. It appears that concerns regarding the lack of public acceptance of H_2 projects are not presently at the forefront for participants. Conversely, the study uncovers influential factors previously undisclosed. Key among these are factors on the "input" side, such as the macroeconomic impacts (e.g., electricity price, inflation rate) and the impetus fuelled by the EU's endeavours to diminish energy import dependency. These input variables give rise to output factors like the "Threat of de-industrialization" and the " Risk " factor associated with H_2 projects. Additionally, heightened "administrative burdens" contribute to increased project risk and extended timelines. On the "output" front, paramount importance is accorded to the presence of confirmed first demand for H_2, encapsulated in "Demand H_2", alongside supply. Essentially, a certain "Degree of a liquid market (including infrastructure)" proves indispensable.

7.4. Discussion of causal relationships and system theory

As stated in Section 6.6, attempting to investigate the detailed causal mechanisms between the elements in a deeper level of detail proved to be challenging, despite the desire to gain a deeper understanding of how the H_2 economy business model functions.

The results presented in Table 8 and Appendix 6 highlight the main factors and their impact, with Appendix 6 showing causal relations categorised in stratified layers. While these compilations are informative and have not been published before (to the best of the author's knowledge), it is evident that the results in the tables mainly demonstrate causality between individual variables or smaller groups of variables.

For instance, Table 8, row 1 informs about the “Market design”, which encompasses several factors, such as the CCfDs (Carbon contracts for difference, see Section 2.4.4), CO_2 pricing and other factors. The "Market design" influences the value attributed to green hydrogen, impacts the emergence of a liquid market, and reduces project risks if the market design is favourable. Thus, one input factor influences multiple output factors such as the “Demand of H_2”, the “Price of H_2”, the “Risk”, and the “Degree of a liquid market”. Conversely, it is also apparent in the results that one output factor is caused by many input factors. The emergence of a liquid market is caused by many factors; those listed in row 1 and row 3 of Table 8 are just a few causes contributing to this effect.

Furthermore, there is an interplay with business model elements, e.g. the amount of green H_2 that can be offered by the suppliers might co-depend on the maturity of the related technologies and components and, more generally also, the existence of a transport system for H_2 is a cause for the emergence of a liquid market.

While all this information provided is valid, it remains unclear how exactly these factors influence the design of the business models and which specific business model elements are affected. In other words, the question of which conjunctions cause which conditions that favour the emergence of certain business model designs cannot be answered precisely.

In the quest for exploration, it was initially sought to establish a variable-by-variable matrix to discern the interplay between different factors. Regrettably, this approach proved impractical, as resolving the intricate relationships individually appeared unattainable. A second attempt was undertaken using causal chain methods proposed by Miles et al. (2014) to unravel the cause-and-effect dynamics. Despite those efforts, this avenue, too, failed to yield a satisfactory outcome.

These unsatisfying results seem to be caused by the variables not occurring individually, having isolated one-to-one relations to other variables, but having multiple interwoven relationships, feedback loops, etc. The items seem to show systemic behaviour, and a reductionist approach cannot adequately convey the complexity of such a system.

Overall, the reductionist approach of disaggregating the relationships into numerous causal chains and variables and studying numerous isolated conjunctions seems ineffective and does not seem to reflect the reality of the hydrogen economy.

Part 1 of the study introduced the H_2 economy as a complex system, a view confirmed by many participants through their statements (see Chapter 6). The hydrogen economy system comprises numerous interconnected parts and subsystems interacting dynamically and non-linearly across multiple levels. In the following, a brief excursion into systems theory will be discussed and what such a perspective could mean for the further investigation of relationships. The concepts of open systems, non-linear causality, upwards and downwards causation, stratification, equifinality, complex systems and networks (Amaral & Ottino, 2004; Bar-Yam, 2002; Mingers, 2014; Mingers & Standing, 2017) were briefly introduced in Section 3.4 along with key concepts of critical realism. Those concepts were considered to abstract the thematic map (Figure 34) with the aim of achieving a more generalised understanding of the H_2

economy system in relation to the overall research question of how business models for the H_2 economy could function. Taking into account the assumption underlying the study that better business models can be beneficial for the ramp-up of the hydrogen economy (see Chapter 4.4), then one can define the creation of viable business models as the desirable output of the business modelling process, which can be viewed as a system.

Drawing from the hypotheses presented, Figure 34 has been abstracted and viewed as several open systems, that collectively function as an activity system (Zott & Amit, 2010). These systems traverse various hierarchies, engaging in processes, utilising input parameters, undergoing a business model design process, and ultimately yielding viable business model designs (refer to Figure 35). Within these hierarchies, the systems comprise numerous components and sub-models interconnected by diverse relationships. For instance, at the business model design process level, distinct nodes represent key business model elements such as investors, value creation, products, and technologies. These nodes are linked by various relationships, including balancing or reinforcing connections (see Section 3.4). The purposeful activation of a specific set of nodes facilitates the design of viable business models, as illustrated at the lowermost level in Figure 35.

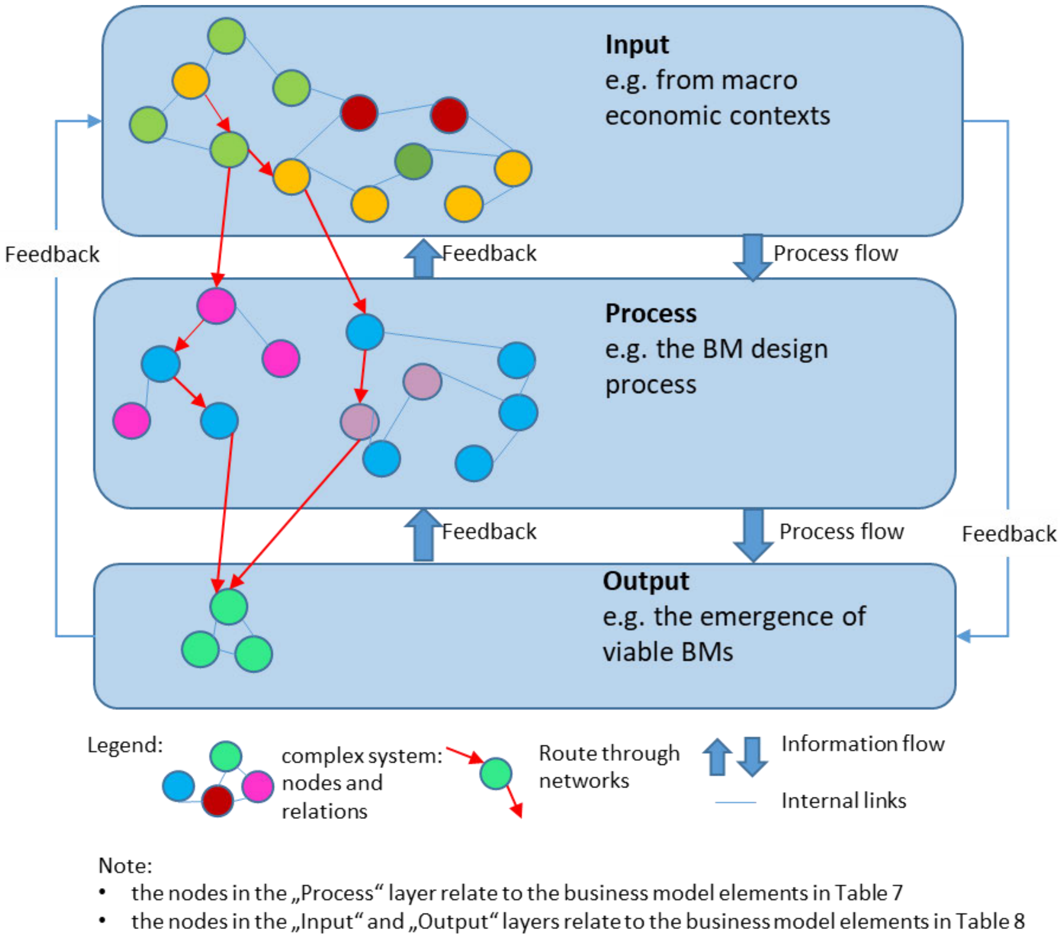


Figure 35 Hypothetical complex system model to approach causality analyses (author's own)

The systems at the hierarchical levels and their components are interconnected, with feedback loops existing between the levels. Essentially, the process-level input parameters are influenced by the top level, where the nodes and systems of the macroeconomic contexts are situated. For instance, European policies and various macroeconomic conditions, such as guidelines RED II / III and emission reduction goals, provide inputs to the process level. However, the process level also provides feedback to the upper level in cases where suitable input parameters are unavailable, and no successful routes lead to a desirable output (i.e. a viable business model design), which can be found through the various networks.

By adopting this systemic view, a holistic approach to explaining causality becomes available. Causality can be described as downward causation (Mingers, 2014); the theoretical concepts mentioned here are briefly introduced in Section 3.4. This means that to get an understanding of an effect, one does not need to drill down to find a single cause; instead, one must consider the entire system and maybe find multiple factors that provoked the effect. The equifinality principle provides information about how many routes through the various networks lead to the desired result. In Figure 35, two different routes, marked by red arrow linkages, lead to the same output. Equifinality and other network parameters, such as the number of nodes involved in successful routes, the degree of connectivity of individual nodes, and the overall path length of successful routes, can help assess the network's stability and success rate (Amaral & Ottino, 2004). Applying these network characteristics hypothetically to the research question on how the business model for the H_2 economy could function, the best conditions for the emergence of many viable business models would be:

- that there are as many successful routes as possible through the various networks.

In practice, this means many viable business models can be designed, e.g. by using various nodes from the input level (e.g. quota obligations for different industries), activating various nodes from the process level (e.g. various choices for value creation) and by doing so several business model designs will become viable.

- that the number of nodes involved in a successful route is as low as possible.

Low numbers of involved nodes mean only a few actors or topics need to be activated to have a viable business model. On the contrary, many nodes involved will likely mean long paths, which in turn might mean complicated setups for business model designs, many parties involved, and many interfaces to be managed.

Investigations about the connectivity of the nodes, i.e., how many links each node has, how often it is used to build successful routes, etc., could also be interesting, as they could give insights about each node's importance.

While these considerations remain speculative, they offer alternative avenues for exploring causality beyond the predominant reductionist methods. Constructing a detailed model of the intricate systems within the H_2 economy undoubtedly demands substantial effort. Nonetheless, if executed effectively, it opens doors to investigating viable business models and a broader spectrum of pertinent inquiries. This expansion into complex systems presents itself as a promising area warranting further investigation (refer to Section 8.5 for more details on potential further research).

7.5. Revision of the conceptual framework

This section presents the development of the conceptual framework, starting from the initial conceptual frameworks (see Sections 2.5 and 2.6) and integrating the findings and insights gained during fieldwork, analysis and discussion.

The initial framework consists of the two tables (Table 2 and Table 3) answering the questions that guided the literature review and the graphical presentation of the business model as an activity system illustrated in Figure 9 (and also in Figure 10 and Figure 11). The initial framework consists of the application of the CIMO – logic (Denyer et al., 2008), of Zott and Amit (2010)‘s view of business models as purposeful activity systems and Casadesus-Masanell and Ricart (2010)’s approach to investigate the business logic of a firm by investigating their strategy and the choices and consequences they took when designing their business models. The initial framework helped to frame and focus the data collection and analysis process. The idea of design elements and design themes of Zott and Amit (2010) was used to identify the elements being present in the business models and the underlying mechanisms of value creation and therefore facilitated the data collection and analysis that led to Table 7. The idea of choices and consequences and feedback loops of Casadesus-Masanell and Ricart (2010) was used to find out about interrelationships, dependencies and sensitivities of business model elements and therefore facilitated the data collection and analysis that led to Table 8. The underlying hypothesis for crafting the initial frameworks was that various business model designs already exist in the various IPCEI projects, which can be investigated, compared, and then potentially advanced. The initial research questions were also aimed at scrutinising existing business models. Section 4.2 contains the initial hypothesis and research questions.

Already during the fieldwork in the screening phase (Chapter 5), it became clear that the project developments and, thus also, the development of the business models were not as advanced as initially hypothesised. It was found that, for the most part, the business models have not yet been designed and that several external factors significantly influence the ramp-up of the hydrogen economy. At the beginning of the main phase, the initial research questions thus were adapted into (see Chapter 6):

RQ 1) What elements are the (future) business models consisting of?

RQ 2) How are those elements interacting?

RQ 3) What business model designs are considered today for upcoming large-scale green hydrogen projects?

The initial graphical conceptual framework, illustrated in Figure 9 (and also in Figure 10 and Figure 11 in Section 2.6), which was based on the assumption that business models existed that could be analysed, was also no longer suitable for the highly exploratory nature of the study.

Developing the new conceptual frameworks for business modelling for H_2 economy – drawing on from theory (Osterwalder et al. (2005), Figure 7)

One of the most notable discoveries from the research is the apparent focus of stakeholders on macro-level considerations rather than delving into micro-level intricacies such as resource planning, pricing strategies, and unique selling propositions. Their primary concerns revolve around external factors like market liquidity for green H_2, subsidies, timeline, and investment risks. These insights are discussed in detail in Section 7.3. For a deeper understanding, we delve into conceptual modelling, which is addressed below. This modelling draws upon theoretical foundations outlined in Section 2.4.2, building upon Osterwalder et al. (2005) business model concept hierarchy (Figure 7), categorising business meta-models and sub-meta-models. The conceptual framework also incorporates insights from Wirtz and Daiser's (2017) integrated business model, which integrates environmental dimensions. Osterwalder et al. (2005) articulate how, on a meta-level, the elements constituting a business model and their interconnections can be defined, elucidating “what elements are to be found in a business model” (p.6) and how they could be modelled. This comprehensive approach aids in understanding the intricate dynamics of business model designs and their broader implications.

Presenting the study results graphically as a business model design process

In the study a number of interlinked business model elements have been found, surprising findings have been discussed in Section 7.3. Furthermore, a number of interlinked influencing factors, have been found, grouped into input and output variables. The factors, their linkages and causalities have been discussed in Section 7.4.

Having identified inputs and outputs, links and the business model as a process, it is argued that the overarching business model concept for the H_2 economy can be modelled as a process. Figure 35 can also be used to explain the H_2 business model design activity as a process. The input variables are the input in the model, the business model elements are the process and the output variables are the output. The process flows from the top to the bottom, there is also feedback flowing back from the bottom to the top. The arrows, i.e. the links are in Figure 35, to indicate that there is mutual impact and numerous links generate the complexity in the system, this has been discussed in Section 7.4. There is information flowing from the top to the bottom in the model (blue arrows labelled as "Process flow" in Figure 35) and there is also information flowing back from the bottom to the top (blue arrows labelled as "Feedback" in Figure 35).

Some input factors do not only affect the business model elements, but also have a direct impact on the output factors and are also internally interlinked. For example, the input variable "Market design" (variable 1, Table 8) influences directly the output variable "Demand H_2" (variable 9,Table 8). There are also numerous feedback loops affecting the system behaviour. For example, there is feedback from the output variables to the business elements in the process, e.g. if the "Economics of business" (variable 13, Table 8) are improving, then the chances to find investors and financiers (element 2, Table 7) are also improving.

Figure 36 shows the meta - model filled with the study results. The business model elements, arranged in the centre of the graphic come from Table 7, the input and output factors / variables (brown elliptical shapes, Figure 36) arranged above and below the business model elements come from Table 8. Like Figure 35, Figure 36 also visualises business model designing for the H_2 economy as a process, but Figure 36 is more precise and populated with the study's results for factors and BM elements. The main flow for the process is from top to bottom, following the blue arrow in Figure 36. This is a simplified representation compared to Figure 35, as Figure 35 emphasizes the systemic features and characteristics by showing that there are multiple further connections and feedback loops in the system. Figure 36 can be interpreted as a process model of how the business model design process for large-scale H_2 projects currently works: The input factors and variables at the top of the graphic can be regarded as the starting point for the business model design activities. They activate, trigger and moderate the interactions of the business model elements in the centre of the graphic. As a response to the factors and variables a suitable assembly of business model elements (centre of Figure 36) is selected and brought into relation to each other to generate the best achievable output, depicted as output factors / variables at the bottom of Figure 36. This description of the business model design process is simplified to the extent that it does not describe that not all factors and business model elements are always applicable in every case, Figure 37 and the associated explanations provide further details on these aspects.

Figure 36 shows the study results, highlighting business model elements that were not expected, but have been present in the data, (red filled shapes labelled as "BM element additional") and also identifying business model elements that could have been expected based on the literature review, but were missing in the data (white filled shapes labelled as "BM element missing"). The absence or additional occurrence of business model elements is attributed to the novelty of the business in the H_2 economy. It is deemed to be a temporary phenomenon and analysed in more detail in Section 7.3 and 8.3.2.3.

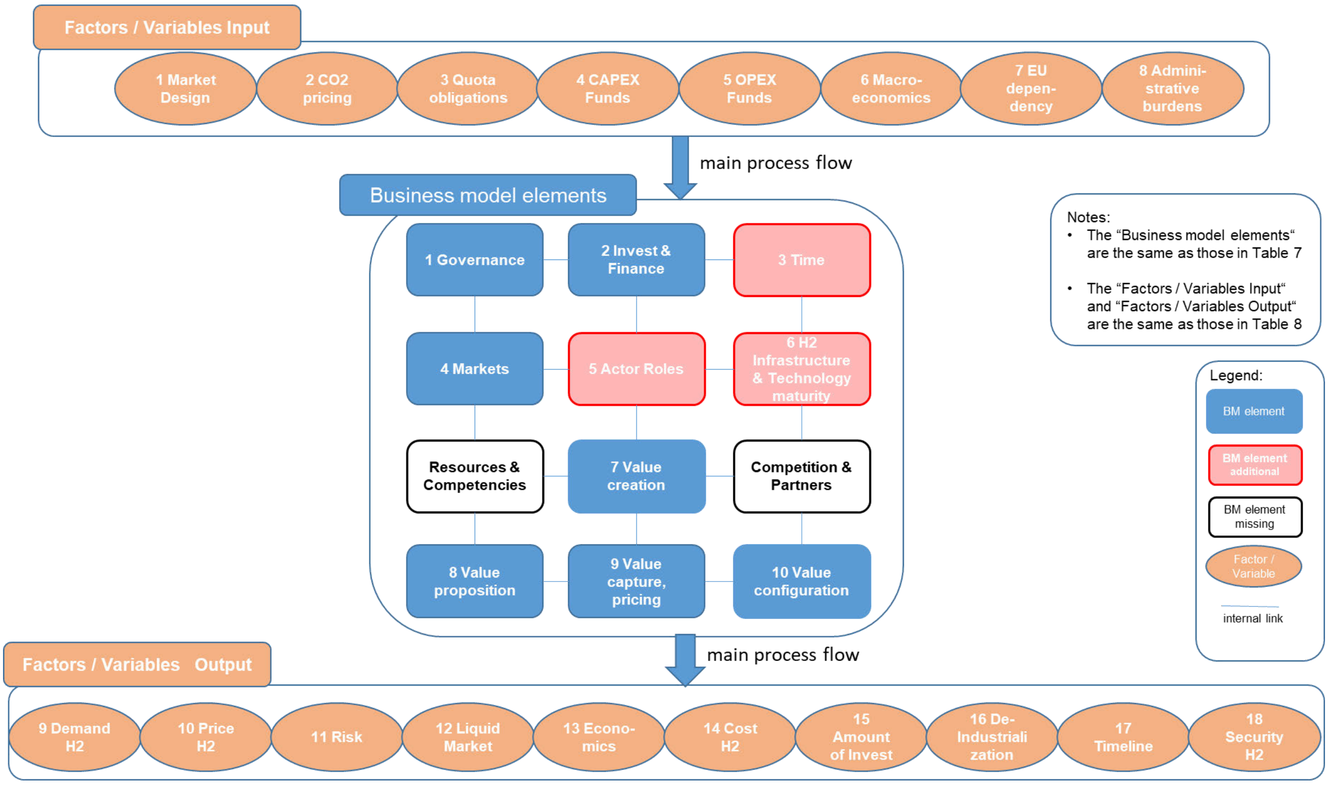


Figure 36 Business meta-model of H_2 economy filled with study results (author's own)

Further conceptualising the business model design process for H_2 economy by abstracting from study results

Also, level two of the hierarchical business model concept of Osterwalder et al. (2005), presented in Figure 7), has been adopted to conceptualise the findings further. Level two is still on the conceptual level but describes types of business models that resemble each other and have common characteristics. Osterwalder et al. (2005) call them “taxonomy of types” or “sub-(meta)-models, parts of Osterwalder et al. (2005) ‘s definition of what a business model is, is adopted:

> A business model is a conceptual tool containing a set of objects, concepts and their relationships with the objective to express the business logic of a specific firm. (Osterwalder et al., 2005, p. 3)

Applying this definition to the findings of the study, Osterwalder et al.’s “set of objects” corresponds to the ten business model elements identified for the H_2 economy, compiled in Table 7 and also to the eighteen internal and external factors, compiled in Table 8. “Their relationships” and how those “set of objects” is composed form the “business logic”. The “business logic” for this study is to be understood as a selection of the business model elements and a selection of the factors that work together purposefully and together form a viable and also feasible business model design.

Two additional scholars will be engaged to encapsulate the evolved perspective. Initially, Casadesus-Masanell and Ricart (2010) present insightful notions concerning choices and their ramifications, offering a spectrum of possibilities for configuring business models. Following them, Baden-Fuller and Morgan (2010) introduce the metaphor of business models as recipes, likening them to culinary creations crafted from diverse ingredients. Just as some recipes yield delectable dishes while others fall short, certain business models thrive while others falter, potentially due to the absence of key components in their formulation.

The thematic map (Figure 34 in Section 6.6) illustrated the main findings of the phase 2 of the study, Figure 37 below, enhances the thematic map into a conceptual framework for business model design process for the H_2 economy and also represent level 2 and 3 of the Osterwalder et al. (2005) framework reproduced in this thesis in Figure 7.

The table of business model elements (Table 7) and the table of factors (Table 8) present the ingredients or the choices and consequences where business model designers find orientation in which elements and features are, in principle, available for designing business models for the H_2 economy. But not all of those options are selectable at all times and under any circumstances (see uncoloured shapes in Figure 37); for example, some funding programs might not be launched yet (see Table 8, variable 4 “Capex funds”, for example), some legal structures for the project company might not be available, because no partners are willing to form a JV (see Table 7, parameters for dimension 1 “Governance” for example). A purposeful selection and linking of the choices might lead to a viable business logic, resulting in a feasible business model.

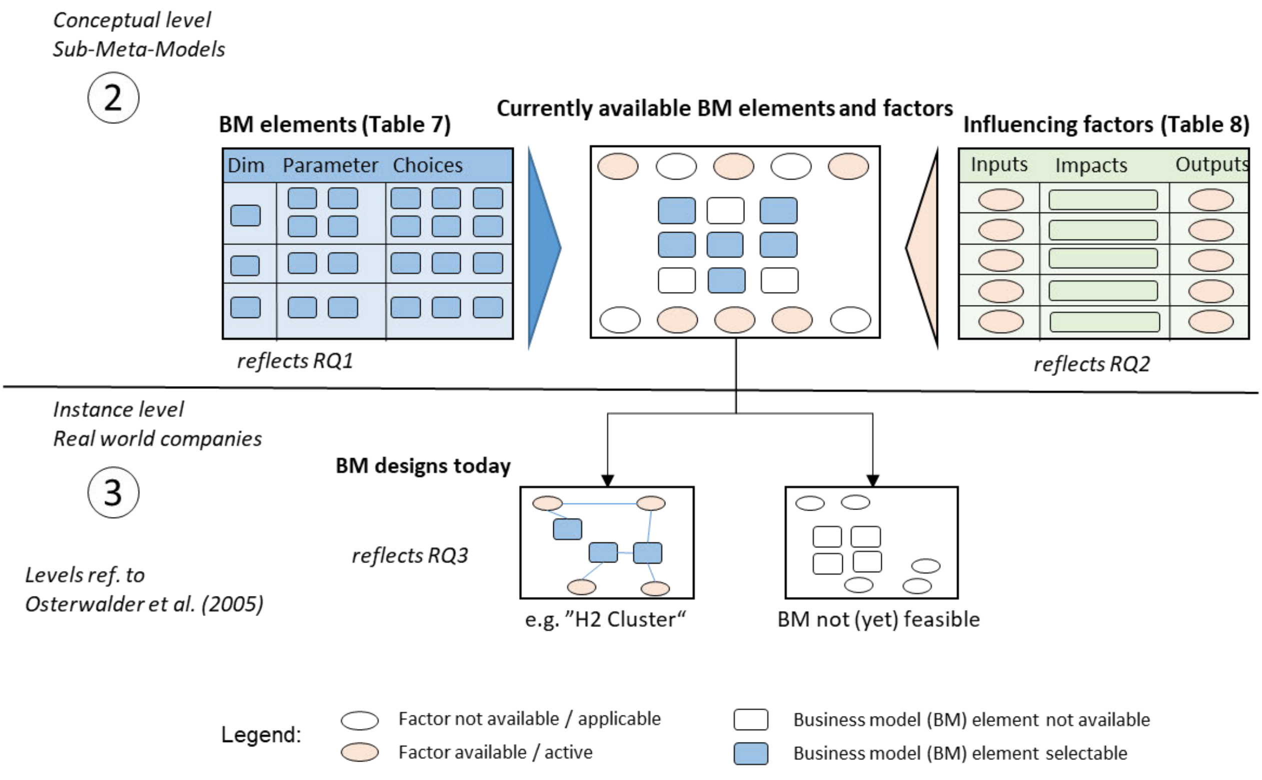


Figure 37 Revised conceptual framework business model design process for the H_2 economy (author's own)

Under the current regulatory framework and with the currently available H_2 infrastructure, only business models that do not require a large H_2 transport or storage infrastructure are feasible. These "H_2 Cluster" business models are described in Section 6.5 and are also the answer to research question RQ 3).

Figure 37 illustrates a meticulously crafted business model design process, meticulously developed through a synthesis of empirical insights and academic principles. This delineated process offers a pragmatic framework tailored for immediate application within the H_2 economy. Guided by the interplay of available options and contextual factors, it navigates the landscape of business model possibilities. Notably, this approach remains pertinent under prevailing conditions characterised by the absence of a stable regulatory framework, the nascent nature of market dynamics in the hydrogen sector, and the inadequacy of infrastructure supporting H_2. The conceptual models (Figure 35, Figure 36 and Figure 37) and the related tables (Table 7 and 8) can be used as a toolbox by companies when considering to step into the hydrogen economy. The models can facilitate business model design activities and help to grasp the complexity of the hydrogen economy mentioned by many participants. In Section 8.3.4. these outcomes have been contextualised and a user guide has been developed.

7.6. Generalisations from the results

Generalisations from qualitative case studies are controversially discussed among scholars (e.g. Bryman & Bell, 2015; Yin, 2018). According to scholarly discussions, there are questions about how and to what extent the results of qualitative case studies can be transferred to other cases, as also explained in the sections reflecting on limitations in this research (Section 4.6 and Section 8.4). One possible approach is to make analytical generalisations, which means generalising from theory and claiming theoretical propositions that can be applied to similar contexts or situations (Yin, 2018). It is claimed that several insights and results gained in this study are analytically generalisable. Furthermore, the conceptual models developed in this chapter are also generalisable in that they contribute to knowledge, as further explained in Section 8.3 (not elaborated here). Two examples of generalisable other results are briefly presented below:

(1) The emergence of “interim business model designs”: In Section 6.5 and also in Figure 34 the thematic analysis presents theme 8, business models of 2030 (“BM 2030”) and theme 10, interim business models (“BM Interim”). The analysis suggests

that there is a development of the business model designs to be expected from today until 2030 and that the business model designs of today will not be the same as those of 2030; business model designs in a liquid market design will not be the same than the initial business model designs at the beginning of this market development.

The generalised proposition is that "interim business model designs" are a temporary phenomenon that occurs during the ramp-up phase of new markets, particularly in those introducing new technologies, and disappear when the market development reaches a certain level of maturity. The applicability of this proposition is supported when considering how business model designs have evolved in the realm of historical technical innovations. For example, until the 1970s, it was a common business model in Germany to rent space in freezers owned by the municipality because many households could not afford a privately owned freezer or did not have space for one. This business model naturally disappeared when freezers became smaller and more affordable for private households.

(2) The “expansion of selectable choices” when markets are deregulated. Sections 6.5 and 7.5 explain that today only very few business models are feasible, and this is also because many regulations exist that prevent business (see Section 6.4.2).

The overarching principle here is that with the market's maturation, an expanding array of business model designs becomes viable. This assertion finds solid footing in historical precedent. Considered, for instance, the landscape of energy provision in Germany and Europe just a few years prior. Regulatory constraints barred consumers from selecting their electricity provider freely, constraining them to their local supplier. Fast forward to today, and these regulatory shackles have been lifted, granting consumers the liberty to choose their energy supplier. This pivotal shift has catalysed the emergence of diverse business models, empowering stakeholders across the electricity supply chain.

7.7. Concluding the chapter: Answers to the research questions

The focus of the discussion chapter was on reviewing the study's results in light of the initial planning of the study and the revised plans after the screening phase and how the results reflect academic concepts or not.

The initial design of the study was based on the underlying assumption that a variety of business model designs exist for the IPCEI projects that can be investigated, and recommendations can then be derived to advance the business models. However, it was learned during the screening phase that the hydrogen projects are not yet far enough developed and that there are no business model designs for investigation yet. Consequently, the central research question has been refined to investigate what business logic enables viable business models instead of investigating the existing business models. Also, the aim of the study has been refined from “advancing something that already exists” towards “understand and assess something that is going to be”, namely business models in the H_2 economy. Although this might appear to be a major change that had to happen to the research design, in fact, it was not. The research sub-questions about business elements needed for viable business models and factors that drive and hamper the business model design stayed the same. They became more important, while the question about the business model designs that are already considered today became less important, as there are nearly any.

Critically reconsidering to what extent the revised research sub-questions have been answered, there is to be distinguished between the sub–questions.

The assertion is that the question of what elements comprise business models has been fully addressed. Business model dimensions, their current potential parameters, and a wide range of currently available characteristics, choices, and features have been compiled (Table 7). The comparison to theoretical concepts in Section 7.3 has further contributed to the answer by identifying elements that may only be temporarily relevant and anticipating elements that may become relevant in the future.

It is also confirmed that the third research question concerning the current business model designs under consideration has been thoroughly explored. Among these, only one business model stands out where the development of a viable business logic is presently feasible (refer to Section 6.5). Although this finding may appear modest at first glance, its significance is amplified by its theoretical underpinnings in selectable options and insights from complex system theories (as discussed in Section 7.4). These theoretical foundations have substantially enhanced the comprehension of the context and contributed significantly to conceptualising the business model design process (Figure 37).

The second research question, about how the elements interact, including the factors/variables found (Table 8), could not be answered to the full extent. The available tools during research have been those proposed by Miles et al. (2014) in their book “Qualitative Data Analysis – A Methods Sourcebook”, explaining causality by linear, simplified approaches. These approaches delivered several variables, including their general causal relations, indicators, and impact, as documented in Table 8. However, these methods fall short if non-linear causalities and cross-system correlations are to be explained (see Section 7.4). Thus, for this research question, “epistemological knowledge”, i.e. to know WHY something is happening (Mingers, 2014, pp. 188-189), could not be achieved (see also Section 3.4 for concepts of knowledge).

The central research question, that is, what business logic enables viable business models, can be answered by aggregating the answers to the sub-questions. According to the results of the research, the following key logic principles are derived that seem to apply to the market ramp-up phase:

- **Understand complexity:** Project actors need to understand the complete set of influencing factors and variables that apply to their project to design business models effectively. They also need to understand the entire process and that their projects are underlying a significant complexity (Figure 35).
- **Ensure internal feasibility:** The business model design for the project must be feasible; there must be at least one available choice for each business model dimension. Concretely, referring to Table 7 this means there needs to be governance for the project, finance for the project, appropriate scheduling for the project, etc. Each of the ten business model elements must be configured and populated.
- **Ensure external (value chain integration) compatibility:** Not only does the business model design for the project itself need to be feasible and viable, but the same applies to the related value chain. That means the project actors need to ensure that beyond their project's boundaries, the upstream and downstream value-creation steps also take place within the applicable framework.
- **Build in flexibility for value creation:** It seems that all topics related to value are still very volatile and subject to major changes. This applies to both the business model design for the project’s internal set-up for value proposition, and value captures, etc. (see elements 7, 8, 9 and 10 in Table 7) and also for

the external opportunities to generate that depend on many macroeconomic factors (see factors 1, 2, 3, 9, 10 etc. in Table 8). Therefore, a business model that is adaptable in its design for value creation, value proposition, etc., seems to be recommendable for the phase of the market ramp-up.

Some results of the study are related to the terms “feasibility” and “viability”, therefore the understanding of these terms for this study is briefly defined and differentiated: In the context of H_2 projects, “feasibility” refers to the practicality and achievability of implementing a specific business model within the constraints of available resources, technology, and market conditions. “Feasibility” assesses whether the proposed model can be successfully executed and sustained over time. Whereas “viability” pertains to the long-term sustainability and profitability of the business model, taking into account factors such as market demand, competitive landscape, and financial performance. While “feasibility” focuses on the initial implementation phase, “viability” considers the overall success and endurance of the business model in generating value and achieving strategic objectives in the H_2 economy.

Table 10 summarises the research questions and the answers.

Table 10 Answers to the research questions (author's own)

Research question	Answer	Assessm.
RQ 0: What is the implementation status of the German IPCEI projects?	The status is of the implementation is 2 years behind the expectations, due to many changes in the projects and in the IPCEI program since its launch in 2021. The actors are highly dissatisfied with the administrative processes. Chapter 5 presents the full results of the screening phase.	Fully answered
RQ 1: What elements are the (future) business models consisting of?	10 elements, 43 parameters and >50 design choices have been identified; Section 6.3 and Table 7 present the full results. Additional elements, "Time", "Maturity of technology", "Actor roles" have been identified and understood. Missing elements "Resources & Competencies", "Competition and Partners" have been identified and understood. Section 8.3.2.3 discusses the findings of additional and missing business model elements in more detail.	Fully answered
RQ 2: How are those elements interacting?	18 influencing factors / variables have been identified and categorised either as input or output factors. Those factors impact and determine the interaction of the elements in various ways. Section 6.4 and Table 8 present the full results. Exploring causal relationships between elements using methods from complex systems theory could provide further valuable insights. This concept is discussed in Section 7.4, with recommendations for future research outlined in Section 8.5.	Fully answered
RQ 3: What business model designs are considered today for upcoming large scale green hydrogen projects?	It has been found that today only business models that do not need an H_2 pipeline grid are feasible. The interviewees have called them "Local H_2 hubs", "H_2 clusters" or "H_2 ecosystems"; Section 6.5 presents the full results. Conceptual models (Figure 35 to Figure 37 and Figure 41) visualizing the current business logic have been developed. Those models can help users to guide business modelling activities; Section 8.3.4 presents the "user guide".	Fully answered
What business logic enables viable business models for large scale green H_2 projects? 1.The complexity of H_2 project business modelling needs to be fully understood. 2.The business model design needs to be feasible. 3.The business model design must be compatible over the complete value chain. 4.Design for the elements referring to VALUE should be adaptable to external changes taking place in the macroeconomics and also to internal changes taking place in the actor role or model for value configuration in the project's company.		

8. Conclusion

8.1. Introduction into the chapter

This chapter marks the conclusion of the study. It begins by providing an overview of the study's aim, objectives, and motivation, followed by a brief summary of the design and methods used for data collection and analysis to present the findings and results. The main focus of the chapter is on the contributions that this study makes to both theory and practice.

Section 8.3.1 delves into the significant contributions to theory, enriching the understanding of business model innovation within the context of the burgeoning hydrogen economy's market expansion phase. The section elucidates the conceptualization of business modelling design specifically tailored for this dynamic landscape. This encompasses the development of an industry-specific taxonomy and the delineation of the current pertinent conditions within this partially regulated domain. Moving forward to Section 8.3.2, the focus shifts to the practical implications of the findings. These insights are poised to offer valuable guidance to companies contemplating entry into the green hydrogen market. Notably, comprehensive insights are provided into the project development processes essential for large-scale hydrogen initiatives, alongside an exploration of the myriad choices and features available for crafting bespoke business models within this domain.

The chapter also addresses the limitations of the study and suggests potential areas for further research. Finally, it concludes with a personal reflection from the author on her research journey.

8.2. Overview over the study

8.2.1. Theoretical part: Aim, objectives, motivation and study design

Aim, objectives and motivation

The purpose of this study is to investigate and understand business modelling for the H_2 economy. Therefore, the central research question aims to address what business logic enables viable business models for large scale green H_2 projects. In this context, business logic means the composition of various elements into a functioning business model for entrepreneurs or companies already engaged in the hydrogen business or planning to engage.

The theoretical motivation behind this study is to examine the business models for green hydrogen projects, emphasizing their economic significance, role in decarbonisation efforts, and alignment with the EU climate goals (UN, 2015) and UN Sustainable Development Goals (UN, 2016), thereby contributing to a sustainable and environmentally friendly future.

The practical motivation for the study is the mismatch between government-published plans for hydrogen projects and the actual implementation speed and degree of these projects. Initially, at the beginning of the study in October 2020, this mismatch was perceived by the author of this thesis, who works in the hydrogen business and has been personally affected by delayed and cancelled projects. Meanwhile, this mismatch is confirmed by publicly available sources (Hydrogen Council, 2023; IEA, 2023a). This discrepancy, along with the underlying proposition that appropriate business models could facilitate the ramp-up, forms the basis for the design of this study.

Study design and data collection and analysis

The study was designed as a qualitative case study conducting an enquiry into the German IPCEI H_2 projects (BMWI, 2021b). The fieldwork for the study was divided into two phases.

Phase 1, the "screening phase," provided an overview of the status of the original 62 German H_2 IPCEI (Important Projects of Common European Interest) projects and informed about the type and extent of available data in the field. The IPCEI program is an EU initiative in which selected projects receive funding beyond the usual level of EU state aid law to develop crucial technologies for the EU market in Europe (BMWK, 2023e).

The screening phase culminated in an anonymous survey, which drew participation from up to 30 project stakeholders. The invaluable insights garnered during this phase served as a cornerstone for refining the design of phase 2. This pivotal phase encompassed a multifaceted approach, including conducting 16 semi-structured interviews with project actors and various stakeholders, attending three pertinent conferences, and collecting 17 conference contributions and five recommended documents identified by interviewees as pertinent to the research endeavour. In total, the main phase amassed a robust data pool comprising 38 files. Among these were 702 minutes of recorded audio interviews and 425 minutes of audio and video materials from the conferences. Subsequently, the interview data and conference audios underwent thorough transcription and importation into NVIVO for analysis. The data were then subjected to coding and subsequent thematic analysis, adhering to the methodological framework outlined by Braun and Clarke (2006). The analytical process employed a deductive approach at a macro level, supplemented by an inductive approach at more granular levels. This methodology involved the formulation of research questions (RQ) and a set of *a priori* codes to guide the initial data analysis. However, the emergence of themes under each research question was primarily driven by inductive reasoning. The overarching aim of the study, along with its objectives and research questions, are succinctly presented in Figure 38, which provides a comprehensive overview of the study's direction and focus.

Critical assessment of effectiveness

The data collection and analysis process is assessed as effective and robust in achieving the study's objectives. The selection of interviewees, events, and documents was done deliberately to ensure a comprehensive view of the topic, incorporating diverse perspectives. The interviews were comprehensive and flexible enough to allow for the emergence of individual insights. The participants in the interviews, surveys, and other contributions represent stakeholder groups that can influence market ramp-up, and their statements are deemed relevant and important. The interviews were concluded after 16 participants, even though additional interviewees were available, as the saturation point had been reached, and no new information was added. The data analysis is regarded as transparent and auditable, with various software supporting the analysis and evaluation processes. The survey was conducted and evaluated using Tivian Unipark software, and the transcripts and other materials were coded and analysed using NVIVO. The entire process is documented in Section 5.3 and 6.2, providing a comprehensive record of the analysis steps through the use of software, such as the codebook for theme development for example (Appendix 5).

8.2.2. Practical part: Findings, results, answers to research questions

Findings screening phase (phase 1)

The screening phase investigated and assessed the implementation status of the German H_2 IPCEI projects.

The findings reveal that the projects and their stakeholders have faced significant challenges, including changes in project consortia, financing schemes, and scopes. Project progress has fallen behind schedule, leading to dissatisfaction among the stakeholders in particular with EU and national requirements in the IPCEI process. As of summer 2023, only a few projects had received EU notification and are awaiting approval for national funding. The results show that the business models of individual projects are less developed than expected. Additionally, external factors beyond the control of project actors have a more substantial impact on business model design than initially assumed. The objective, research question, and results of the screening phase are presented in a concise form in Figure 38, represented by green-shaded boxes.

Findings main phase (phase 2)

The main phase analysed and interpreted the qualitative data of the interviews, the conference contributions and the documents that formed the data pool (see previous section), aiming to find out about the composition of business models and aiming to find out about how the composing elements interact. A special focus was put on learning more about the external factors and their impact, which were identified in the screening phase. The objectives, research questions, and results of the main phase are presented in a concise form in Figure 38, represented by blue-shaded boxes.

Ten main themes were developed from the data through the reflexive thematic analysis (Braun & Clarke, 2006; Byrne, 2022) and allocated to the three research questions (RQs).

Four of the ten main themes have been allocated to RQ1, that is, “What elements are the (future) business models consisting of?”. The main themes allocated to this question are

(1) INVESTMENT FINANCE GOVERNANCE

(2) ACTORS & MARKETS

(3) VALUE and

(4) TECHNOLOGY & INFRASTRUCTURE

The data's depth and quantity allowed for a more detailed investigation of the potential elements within a business model. The summary of this analytical work is presented in Section 6.3.5. and Table 7. Table 7 shows the four main themes and their further break down into ten business model dimensions further cascading into 43 related parameters. In addition, characteristics or features that map out the potential range of choices for the related parameter are shown in Table 7. The following example illustrates how to interpret the entries in Table 7: For the main Theme 4, VALUE, four dimensions, in other words, business model elements have been subsumed, these are element 7 “Value creation”, element 8 “Value proposition”, element 9 “Value capture” and element 10 “Value configuration”. A further breakdown of element 7, “Value creation”, shows that value can be created through several parameters, such as H_2 sale, H_2 transport, H_2 storage, etc. The individual parameters have different characteristics or features, also listed in Table 7. For example, the parameter “H_2 transport” can generate values through grid fees, by building the connection points for customers, and by transporting H_2 derivatives.

The findings presented herein thoroughly examine the key components underpinning business models within the hydrogen economy, as articulated by the participants. A wealth of insights has been unearthed through rigorous analysis, offering both practical applications and theoretical significance. Notably, the exploration uncovered unexpected nuances and revelations. Noteworthy among these is the emergence of additional business model elements, denoted in red within Table 7, as well as the absence of elements that one would typically expect because they are often outlined in the existing literature. These intriguing discoveries are thoughtfully discussed and contextualised in Chapter 7, contributing substantially to the subsequent sections of this presentation.

Three of the ten main themes have been allocated to the RQ2: "How are those elements interacting?". The main themes allocated to this question are

(5) POLICIES & REGULATORY

(6) OBSTRUCTIONS and

(7) MOTIVATORS

The narratives of the three themes were analysed with a focus on finding out about influencing factors, causal relationships and interactions. The summary of this analytical work is presented in Section 6.4, Table 8 and Appendix 6 . The findings could be categorised hierarchically depending on their causal mechanisms and structure into overarching components, directly influencing factors and observable impacts and consequences. In total, eight overarching structures and mechanisms have been formulated that generate several impacting factors, which in turn trigger several effects. Table 8 shows all the influencing elements extracted from the data. The 18 factors synthesised from the most frequently mentioned influences were prioritised and used for further analysis that actually addressed the research question, that is, to find out about the interaction of the business model elements. Following Miles et al. (2014) suggestions for methods of explaining, the factors have been sorted into variables that can be predominantly considered as inputs and those that can be predominantly considered as output when viewing the business modelling activity as a process. A brief example of how to read Table 8 should facilitate the understanding of the further explanations. For example, the input variable 1, “Market Design”, with its characteristics of how to price CO_2 emissions and its framework policies for the CCfDs (Carbon Contracts for Difference), (BMWK, 2023b) impacts the value of green H_2 and also the demand for H_2, which is created in the market. These impacts also interact with other output variables such as variable 11, “Risk”.

Table 8 offers a comprehensive overview of drivers, obstacles, and underlying causal mechanisms, presenting valuable and innovative insights for practitioners. While the study successfully pinpointed primary causal relationships, fully unravelling the intricate interdependencies and interactions among business model elements and their macroeconomic impact remained elusive. Section 7.4 presents a potentially enhanced methodology for investigating these causalities holistically.

However, the factor analyses also yielded surprising results. For example, most of the factors identified are external factors; internal factors, such as resources and organisational structures, do not appear to play a significant role according to the participant’s perspective. Once again, these and other results are discussed and contextualised in the Chapter; they form part of the contribution presented in the next section.

The third research question (RQ3), “What business model designs are considered today for upcoming large-scale green hydrogen projects?” delivered less content than expected. Nonetheless, three main themes have been allocated to that question, with BM standing for business model.

(8) BM 2030

(9) BM CAUSALITIES and

(10) BM INTERIM

The three themes were analysed, and in essence, it was found that today, the participants only expressed one idea about a business model design, where, already today or in the near future, favourable pre-conditions are to be expected. These are business models for establishing local H_2 hubs or local H_2 clusters. The complete findings and results are summarised in Sections 6.5 and 6.6.

The outcome of this research question seems somewhat limited. Nevertheless, it is considered valid and meaningful because it seems logical that actors only see a few potential viable business models today, especially when considering the discussions in Chapter 7 on incomplete and dysfunctional business models.

Answering the research questions

As previously explained, the findings and results effectively addressed the research questions, RQ 0 from the screening phase and RQ1 to RQ3 from the main phase. The answer to the central research question, that is, what business logic enables viable business models for large-scale green H_2 projects, is derived by amalgamating, condensing and reflecting on the answers for the other research questions. Four statements can be made:

(1) Those aiming to set up a green hydrogen project as a business need to fully understand the complexity, variables, business model elements, and relationships that apply to their project to meet all requirements and capitalise on all opportunities.

(2) they need to ensure that their business model is feasible, i.e. practically implementable and executable and complete, meaning each of the ten business model elements needs to be configured with at least one available choice

(3) they also need to ensure that beyond the boundaries of their project, the upstream and downstream value creation steps are also taking place within the applicable framework to avoid infringements

(4) it is recommended to design the element “Value creation” with flexibility to be able to adapt to changing external context

Table 10 in Section 7.7 shows the detailed answers to the research questions, including an assessment of the quality of the answers, Figure 38 presents a condensed form of the answers.

Thematic map and towards conceptual mapping

The intricate relationships among the ten themes unearthed through thematic analysis have been visually represented in a thematic map (Figure 34). This map served as the cornerstone for crafting the conceptual framework for the business model, previewed in Figure 38 (bottom right-hand corner) as the "Business meta-model of H_2 economy." A comprehensive explanation of this model is elaborated in subsequent sections, delving into its pivotal contributions.

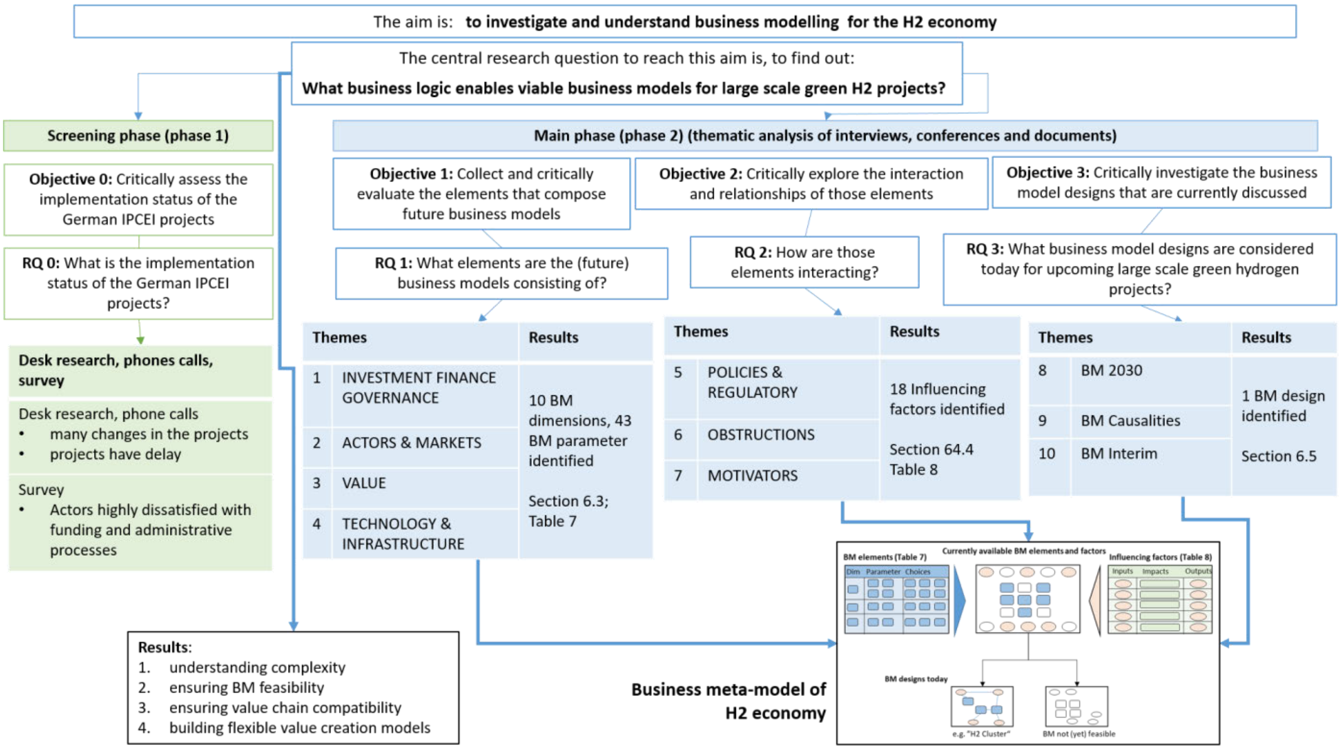


Figure 38 Study overview (author's own)

It must be kept in mind that the findings and results presented in Chapter 6 are purely based on the collected data and the data interpretation; nothing has been added, and nothing has been left out. The data reflects the participants' views at the time of the enquiry, summer 2023.

Chapter 7 juxtaposes the findings from Chapter 6 with established theories to pinpoint disparities and engage in thorough discussion. The synthesis of these analyses, coupled with insights gleaned from relevant literature, serves as the bedrock for the contributions outlined in the subsequent section.

8.3. Contributions

8.3.1. Introduction into the contribution section

As an applied science field, academic business and management research seeks to contribute to theory and practice (e.g. Easterby-Smith et al., 2018; Gray, 2013). This section presents these contributions to theory and practice. These contributions are derived from reflecting and analysing the results in the context of the literature, theories, and conceptual frameworks developed in the discussion chapter (Chapter 7).

The study makes academic contributions to business model research and practical contributions to strategy development and business model design for the H_2 economy. It introduces an empirically developed business modelling framework that spans three hierarchical levels and addresses two steps in the value chain: green hydrogen generation and hydrogen infrastructure, comprising transport and storage. This framework is based on existing knowledge from academic and non-academic sources in the fields of business model frameworks, business model innovation, hydrogen economy, and regulatory environment. The frameworks were built iteratively and evaluated using an inductive, step-wise approach that thoroughly analysed and integrated the study's results. Data were collected and analysed sequentially during the screening phase and the main phase of the study, with various sources of evidence allowing for data triangulation. To the best of the author's knowledge, such a framework has not been published in academic or non-academic literature to date. Figure 39 displays the complete framework developed, serving as a guide through this contribution section.

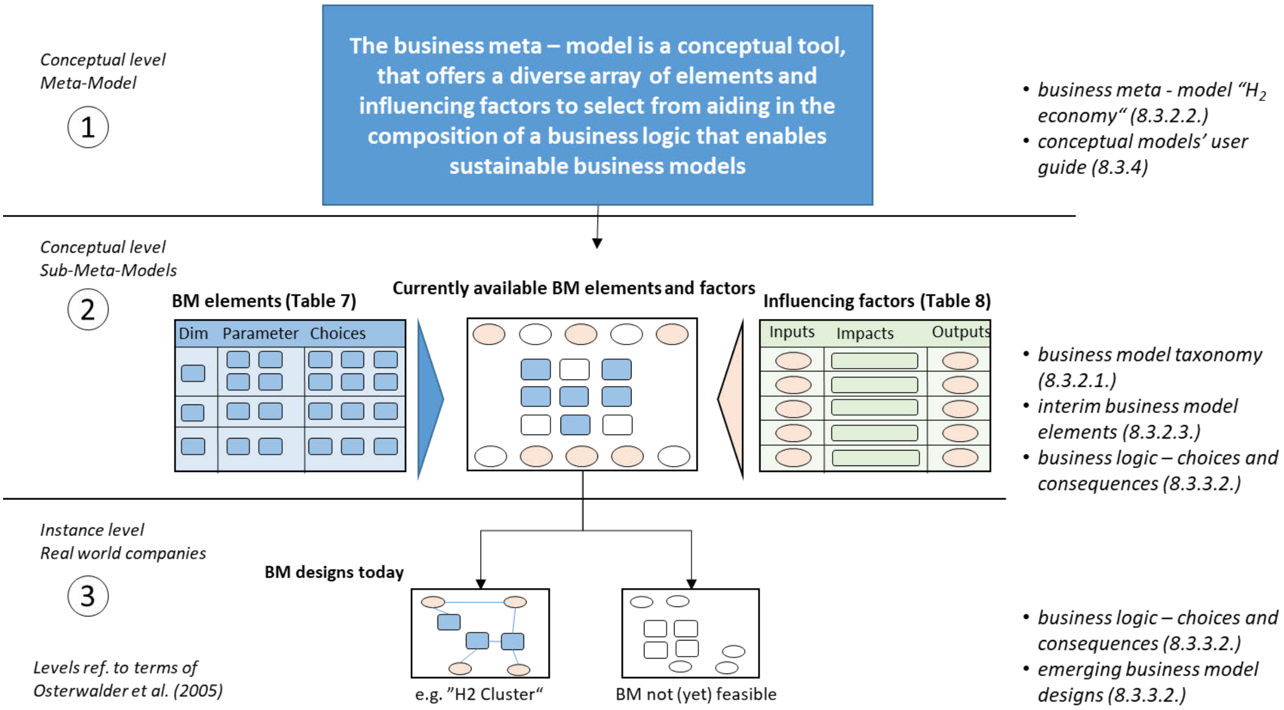


Figure 39 Hierarchical business model framework for H_2 economy (author's own)

At a glance, the study contributes to knowledge by:

- the hierarchical business model framework for H_2 economy as depicted in Figure 39 and introduced in 8.3.2
- the following contributions primarily to theory are explained in the following subsections:
  - the introduction of the H_2 industry-specific business model taxonomies, explained in Section 8.3.2.1
  - the business meta–model for the H_2 economy, a contribution mainly to theory, explained in Section 8.3.2.2

    - the identification of surprising business model elements, additional ones and missing ones, a contribution mainly to theory, explained in Section 8.3.2.3

- The following contributions primarily to practice are explained in the following subsections:
    - the collection of business elements and influencing variables and their relationships and interplay, illustrated in the level 2 part of Figure 39. These interactions can express how the business logic could work and create functioning business models, illustrated in the level 3 part of Figure 39. This knowledge is regarded as primarily a contribution to practice has it can help managers to learn about the choices available or not available and help them to decide to enter the H_2 economy business or not. It is explained in Section 8.3.3.2.
    - Valorising the conceptual models depicted in the Figures 35, 36 and 37 for practical use by providing a "user guide" presented in Section 8.3.4

Furthermore, this study enriches practical insights by providing a comprehensive update on the progress of the IPCEI projects, a crucial initiative selected by the German government two years ago (BMWI, 2021a). Referenced in Section 8.3.3.1, this data illuminates intricate details of project advancement within the industry. Such clarity aids firms in formulating strategic decisions regarding their potential entry into this sector.

These main contributions are further categorised into theoretical contributions presented in 8.3.2 and practical implications presented in 8.3.3. and its related sub-sections.

To the best of the author's knowledge, this study is the first of its kind to explore empirically the status of business model development for large-scale green hydrogen generation and transport projects for Germany through a case study.

8.3.2. Contributions to Theory

This section presents three contributions to theory:

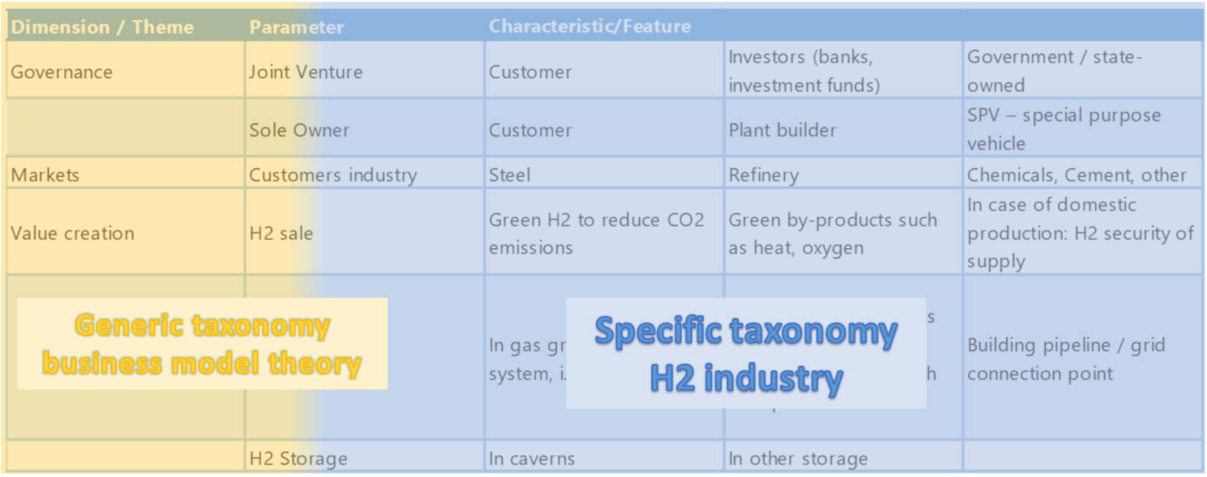
(1) Proposing a **business model taxonomy** tailored for the hydrogen industry

(2) Proposing a **hierarchical conceptual business meta-model** for business models for hydrogen economy by reviewing existing business model research literature, for the first time and
empirically developing a conceptual business meta-model based on real-life perceptions of project actors involved in green hydrogen generation and transport projects

(3) Suggesting the recognition of **interim business models** for designing business models in emerging markets

8.3.2.1. Proposing a business model taxonomy

The first contribution is, that an industry-specific business model taxonomy is proposed. Taxonomy in this context means, to use terminology that is to the point for the industry and can be well understood by practitioners and at the same time is well-grounded in business model theory. Table 7 and Table 8 in Chapter 6 present the industry-specific terminology extracted from the data and contains also the taxonomy stemming from scholarly business model literature to categorize the elements. For example, in Table 7 the column “Dimension” uses terms derived from business model theory, such as “Governance”, “Markets”, “Value creation”. The adjacent column “Parameter” uses partly business model theory terms, such as “Joint Venture”, “Sole Owner”, but also partly H_2 economy specific parameters, such as “H_2 sale”, “H_2 transport”. The terminology of the column “Characteristics/Feature” is fully H_2 industry-specific, describing features of the business model such as “Green H_2 to reduce CO_2 emissions”. Figure 40, which is an excerpt of Table 7 illustrates this scheme “from generic to specific”.



Dimension / Theme	Parameter	Characteristic/Feature		
Governance	Joint Venture	Customer	Investors (banks, investment funds)	Government / state-owned
	Sole Owner	Customer	Plant builder	SPV – special purpose vehicle
Markets	Customers industry	Steel	Refinery	Chemicals, Cement, other
Value creation	H2 sale	Green H2 to reduce CO2 emissions	Green by-products such as heat, oxygen	In case of domestic production: H2 security of supply
		In gas gr… system, i…	…s …h	Building pipeline / grid connection point
	H2 Storage	In caverns	In other storage	

Figure 40 Suggested business model taxonomy (author’s own)

The table of the influencing factors (Table 8) follows the same principle. However, it is even more focused on hydrogen industry-specific terminology.

The scholarly community widely recognises and advocates for the importance of describing business models using industry-specific terminology (Di Tullio et al., 2018; Musulin & Strahonja, 2018; Osterwalder et al., 2005). Examples of this practice exist in various industries, such as e-commerce, airlines, and service businesses (Belussi et al., 2019; Peters, Blohm, & Leimeister, 2015; Petrovic, Kittl, & Teksten, 2001; Rodríguez-García, Orero-Blat, & Palacios-Marqués, 2020). However, there is currently no existing example for the hydrogen sector (to the author's best knowledge). The proposed ontology is based on empirical data and aligns with the terminology used by participants during discussions. In addition to its academic contribution, the proposed taxonomy is expected to have practical utility, as detailed in Section 8.3.3 for practical implications.

The envisioned business model ontology, delineating the core elements of a business model and the various factors that shape it, has been meticulously organised and interconnected. This effort has culminated in the initial iteration of a conceptual business meta-model, which is outlined in the following section.

8.3.2.2. A conceptual business meta-model for the H_2 economy

The study contributes a preliminary conceptual business meta-model for the H_2 economy for the first time. The conceptual framework has been developed empirically based on the perceptions and experiences of project actors involved in real-life projects, trying to implement green hydrogen generation projects or hydrogen transport projects. The practical value for industry practitioners is discussed in Section 8.3.3, while this section focuses on the academic contributions. The theoretical grounding of the study results is extensively discussed in Chapter 7 and briefly summarised below to facilitate understanding of this section.

As outlined in the discussion chapter (Chapter 7), the study’s findings relate to the theoretical ideas of Osterwalder et al. (2005), Osterwalder, Pigneur, Oliveira, and Ferreira (2011), Baden-Fuller and Morgan (2010), Zott and Amit (2010) and Casadesus-Masanell and Ricart (2010). These scholars view business models as simplified tools to comprehend business logic, emphasising the importance of interlinkages between elements and recognising business models as activity systems that create and capture value for their participants (Zott & Amit, 2010). In this study, business logic refers to the purposeful interaction of business model elements with a selection of influencing factors that enable a viable business model design.

The study's findings underscore the significance of the macroeconomic landscape, which comprises the external forces shaping the design of business models, either positively or negatively. This critical aspect, as elucidated in the discussion chapter (Chapter 7), reveals a notable gap within the business model literature. Few frameworks adequately incorporate external factors as pivotal determinants influencing business model design. Through the literature review, only Wirtz and Daiser (2017) and Foss and Saebi (2017) have been identified, integrating macro-level dimensions alongside micro-level ones in their perspectives on business models. Additionally, Schlund et al. (2022), in their investigation of the stakeholder dynamics within the hydrogen market, stress the significance of external factors in shaping the market's trajectory. These studies serve as crucial reference points in understanding how external forces intersect with business model formulation.

Nevertheless, the impact of external influences on business models has been identified as an area that has received limited research attention (Centobelli et al., 2020; Demil & Lecocq, 2010; Wahyono, 2018). Ramdani, Binsaif, and Boukrami (2019) emphasise the need to “look at external drivers of business model innovation and the associated internal changes” (Ramdani et al., 2019, p. 103) and to consider contextual factors such as regulatory frameworks and political initiatives. This reaffirms the theoretical background and highlights the existing gaps in business model research.

The definition for the conceptual business meta–model for the H_2 economy given in level 1 in Figure 39 follows the definitions of Osterwalder et al. (2005) cited in Section 2.4.2, p.45 of this thesis. Figure 36 in Section 7.5 presents the conceptual meta–model filled with the study results. Figure 36 is reproduced below as Figure 41, to ease the reading of this section. A three-fold contribution to academic knowledge is presented that arises from the combination of three concepts: (1) the business model hierarchy concept of Osterwalder et al. (2005), reproduced as Figure 7 in the literature chapter, (2) the ideas of macro and microeconomic dimensions that drive business model innovation according to B. W. Wirtz and P. Daiser (2017) and (3) the ordering of the building blocks as a process of causality following Miles et al. (2014) ideas for "methods for explaining qualitative data" (Miles et al., 2014, pp. 238-246).

In Figure 41, the business model elements, represented by the blue rectangular shapes in the centre of the graphic, compose the business meta-model corresponding to Osterwalder et al. (2005)'s business model hierarchies in Figure 7. The round brown shapes at the top and the bottom part of Figure 41 represent the macroeconomic environmental factors that have been analysed from the data (see Section 6.4) and that are currently strongly impacting the business model designs for the H_2 economy. Following the explanations of Miles et al. (2014) about causal networks, these factors can also be interpreted as variables. Some of them are inputs arranged at the top in Figure 41; some are output variables arranged at the bottom in Figure 41. These input and output factors are at least partially influenced by the operations and interactions of the business model elements in the centre part of Figure 41. The arrows and lines in Figure 41 indicate the relationships between the business model elements (blue shapes) and between the input and business model elements and the output factors.

In essence, Figure 41 provides a comprehensive overview of the current business model elements, pertinent influencing factors, and outcome variables. These components are strategically arranged logically, delineating a process flow that elucidates the existing causal relationships within the analysed sector.

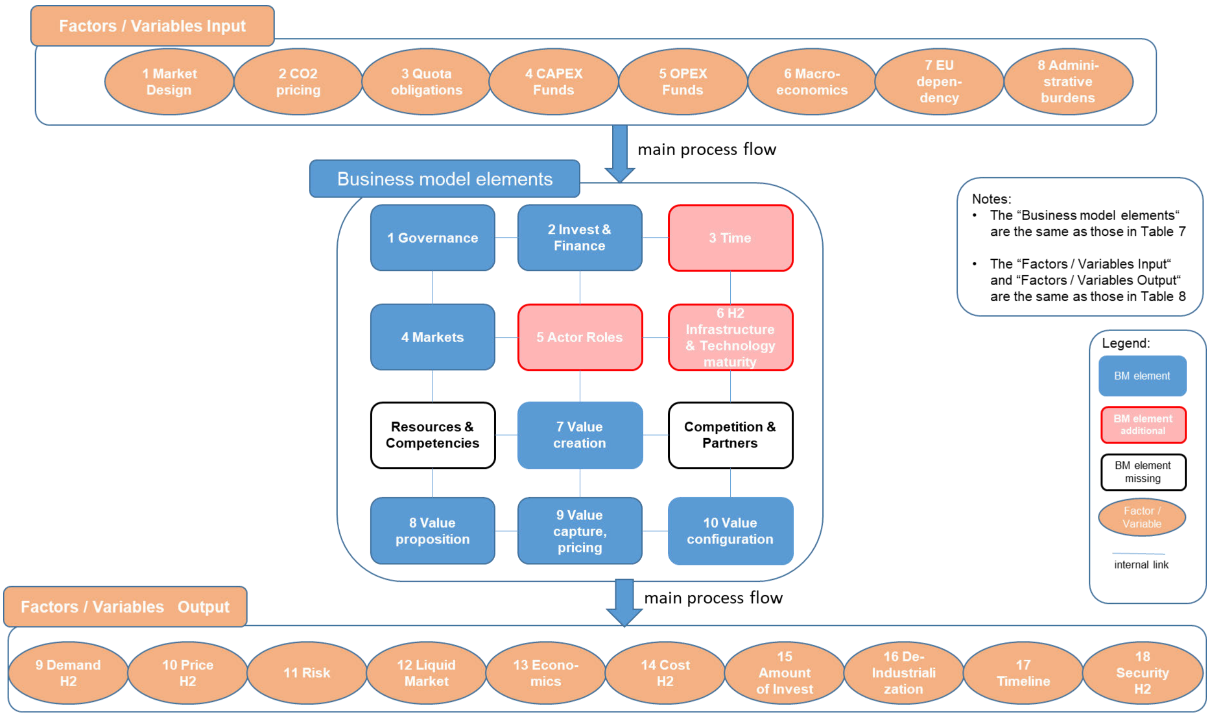


Figure 41 Conceptual business meta-model for H_2 economy (author's own)

The expansion of academic knowledge is achieved by integrating multiple concepts to understand the current business model development in emerging markets comprehensively. It is argued that the developed business meta-model, while simple, is meaningful and offers a better understanding of the situation than the use of only one business model framework, such as the Business Model Navigator (Gassmann, Frankenberger, & Csik, 2013) or the Business Model Canvas (Osterwalder et al., 2011) for example. It is suggested that these existing frameworks have limitations in representing business models heavily influenced by external factors, as is often the case in regulated markets like the energy sector.

Although the simplicity of the graphic in Figure 41 is appealing, it is important to note that the meta-model represents the highest aggregated level of the analysed data and thus only presents the most essential information and correlations. The data collected and analysed provided sufficient richness to extract a higher level of detail about business model elements and influencing factors. The results of this detailed analysis is presented in tabular form (Table 7 and Table 8; Sections 6.3 and 6.4 and Appendix 6).

8.3.2.3. Introducing temporary business model elements

The research revealed some surprising business model elements, labelled as “BM element additional” (red shapes framed in red in Figure 41) and “BM element missing” (white shapes in Figure 41). These elements are surprising, either because they would have been expected and were not found or because they would not have been expected but were found in the data.

The literature review (Chapter 2.4) has gathered various frameworks delineating the architecture of business models. Among these, notable works such as those by Chesbrough and Rosenbloom (2002) and Osterwalder et al. (2011) underscore the significance of "Competition" and "Partners" as fundamental building blocks. Conversely, others, like Demil and Lecocq (2010), Teece (2010), and Zott and Amit (2010), adopt a resource-based perspective, emphasising the assets and structures pivotal for business model design. Given the weight placed on these foundational elements within the literature, finding their absence in this study’s results is striking. Presumed explanations for this discrepancy are deliberated upon in Chapter 7, where one plausible explanation could be attributed to the nascent stage of business development within the H_2 economy.

The additional business model elements, “Time”, “H_2 Infrastructure & Technology maturity”, and “Actor roles”, that are present in the data without being present in the theoretical frameworks also convey interesting insights into the current situation of the H_2 economy. It is perhaps debatable whether "Time" and the other additional elements can be called a business model element or not. But to neglect them would mean to ignore relevant information in the gathered data as both, the additional and the missing business model elements provide interesting insights about what is currently concerning the actors in the development of their business models and what is not concerning them.

The key point here is that during the initial market ramp-up phase of a new technology, certain elements significantly impact the business, at least for a period of time, and must be explicitly considered in the business model design. Conversely, there are business model elements that are extremely important in an established market but appear to have a less significant role during the market ramp-up phase.

The contribution to theory is the acknowledgement of the existence of such “temporary business model elements” that may arise under specific conditions (such as market ramp-up, new technologies, and regulated markets) and need to be considered in early business model designs.

8.3.3. Contributions to Practice

As previously mentioned, there is limited academic literature available on the subject under investigation. However, a growing number of recent publications in the grey literature (Deloitte, 2023; TRANS4REAL, 2023; Worldhydrogenweek, 2023) describe markets, business models, obstacles, and drivers for the hydrogen economy. Some publications claim that it is already today possible to execute a hydrogen project with a viable business case (e.g. Deloitte, 2023; H. Zhang, Yuan, & Tan, 2021), but these are only a few publications, and they either refer to business cases outside Germany or different businesses than those investigated in this study.

The prevailing consensus among numerous papers is that establishing a favourable business case for hydrogen ventures is currently fraught with challenges, if not outright infeasible. These scholarly works argue convincingly that both CAPEX and OPEX funding are indispensable for rendering such projects economically viable. Moreover, they emphasise the criticality of addressing infrastructure hurdles for the sustainable growth of the hydrogen sector. Additionally, they advocate for regulatory frameworks to be streamlined to foster a conducive environment for hydrogen initiatives. In synthesising these insights, it becomes evident that a unified call for action emerges, underscored by a series of recommendations directed towards policymakers and public funding bodies. Notable sources such as DECHEMA (2023), McKinsey (2022), and TRANS4REAL (2023) converge on this point. However, it is noteworthy that the perspectives of the project stakeholders themselves are conspicuously absent in much of the discourse. This study fills this gap by adopting the vantage point of these actors who are deeply entrenched in the day-to-day efforts of advancing their hydrogen projects. Some of them have for years pursued funding avenues and persist in their endeavours to secure investment approval from their respective boards, all aiming to transition from planning to implementation phases.

This study gathered the views of those project actors, their concerns and motivations, and how they see the current status of their projects and the future of their projects.

The information provided has been condensed, interpreted, and synthesised in a structured manner. Project actors and others can now utilise it to gain insights into the current status of large-scale hydrogen projects in Germany. The study provides information about obstacles and drivers for such projects, which is useful for firms and other players who intend to enter the hydrogen industry. Grey literature sources call for more knowledge about and around the “hydrogen system” (TRANS4REAL, 2023). The reports claim that a better understanding is necessary at all levels as a basis for successful business model development:

> A comprehensive understanding of the hydrogen "system" forms the basis for business model development in the field of hydrogen. This includes all production, transport, storage and application options and technologies, regulatory framework conditions, legal requirements, social influencing factors, stakeholders involved and implementation hurdles. There is a significant need for action to create such an understanding for companies to assess potential risks in the market ramp-up of hydrogen and to be able to develop sustainable business models in the long term - socially, ecologically and economically. (TRANS4REAL, 2023)

Whilst the primary practical implication of this study is to broaden the understanding of the hydrogen system in various ways, two specific practical implications are outlined below to explain the potential practical use in more detail:

(1) Providing information about the H_2 IPCEI project status to raise awareness among practitioners about the unique aspects of hydrogen project development processes

(2) Current business logic – which choices for business model design are available

8.3.3.1. Information about the funding process and project progress

The unique practical contribution of this study compared to the sources above in grey literature is that it examines the status of a specific group of projects, the IPCEI projects, from the perspective of the project actors and other stakeholders. The survey results, summarized in Chapter 5 and provided in full detail in Appendix 3 , reveal a high degree of dissatisfaction among the project actors. They are dissatisfied with the processes involved in applying for funding, the associated bureaucratic effort and the presumed effectiveness of the funding. Furthermore, the progress of the projects is also rated as very poor; even two years after the project launch, almost none of the projects have reached a positive final investment decision (see Section 5.4)

This first-hand information is valuable for companies considering involvement in hydrogen projects, whether they are engineering offices, component suppliers, or any consulting company. They need to prepare for long, complex project development times and high levels of uncertainty and risk.

8.3.3.2. Current business logic – available choices and existing influences

The study maps out the business model design process from the conceptual level (see Figure 41) down to the detailed level of potential characteristics of a business model (Table 7; Chapter 6) and down to the detailed impact of potential influencing factors (Table 8, Chapter 6, Appendix 6). These models and the related explanations should help to understand the business logic of the H_2 economy, specifically to understand which choices of business model elements and a combination of influencing variables enable the emergence of viable business models. This business model design process is depicted from level 2 to level 3 in Figure 41, level 3 Figure 41 illustrates the “H_2

Cluster” business model design. The “H_2 Cluster” business model design was one study result and an answer to research question 3, which is described in Section 6.5. This business model design process can help managers understand, analyse and communicate the current business logic of the H_2 business. The tables can be used for orientation and as a source of ideas for creating their own business models for the H_2 economy; they can serve as look-up-catalogues. An example of how the tables can be used is explained below, Figure 42 is an extract from Table 7 and illustrates the usage example. Business model dimension 7, “Value creation” in Figure 42 (respectively Table 7) informs which “Parameters” are eligible to create value, ranging from “H_2 sale” to “CO_2 savings”. The columns headed with “Characteristic/Feature” then give some ideas on how the related parameter could be configured. For instance, the value creation parameter “H_2 transport” could be configured to create value by charging grid feed, transporting H_2 derivatives, or building the customer connection point. Of course, these value-creation options are not mutually exclusive or exhaustive.

No	Dimension / Theme	Parameter	Characteristic/Feature		
	VALUE				
7	Value creation	H2 sale	Green H2 to reduce CO2 emissions	Green by-products such as heat, oxygen	In case of domestic production: H2 security of supply
		H2 transport	In gas grid via entry – exit system, i.e. grid fees	Transport of derivatives or H2 carriers via €/kg transported or per kWh transported	Building pipeline / grid connection point
		H2 Storage	In caverns	In other storage	
		Flexibility for electrical grid	Day and intraday trading	Reserve energy	
		H2 clusters, business ecosystems	sharing of resources	Set up a kind of circular economy for some media/equipment	
		H2 Derivates	Ammonia as raw material or transport means	Methane, methanol as raw material or transport means	
		Heat from H2 burning	In gasturbine	In heat supply applications	
		CO2 savings	ETS	Other quota trading	

Figure 42 Business model elements “H_2 economy” - Extract from Table 7 (author’s own)

Table 8 also serves as a valuable resource for understanding influencing factors pertinent to the discussion. It elucidates the influencing factors themselves and the underlying principles shaping them, along with their potential impact on a business model. By delineating the complex interplay between these factors and the broader macroeconomic landscape, these tables offer insights crucial for managerial decision-making. Such insights, rooted in factors often beyond managerial control, hold significant value in gauging the feasibility of market entry conditions for respective firms.

However, it should be noted that the tables are likely not exhaustive and that the information is also time-sensitive (see also Section 8.4 for limitations of the study). This means the tables cannot be used as catalogues where suitable elements can be selected and combined to form a viable business model. However, the tables should provide enough ideas for practitioners to start thinking from there about the design of their business models and about when the appropriate time for market entry is.

8.3.4. User guide – how to use the conceptual models?

The study's findings have been meticulously documented in a series of tables and charts, each developed, presented and evaluated in the preceding chapters. When combined, these individual outcomes form a robust conceptual framework that empowers business model design activities within the hydrogen economy. The following outcomes are key components of this versatile toolbox:

- Table 7 presenting the dimensions, elements, parameters and available choices for designing business models
- Table 8 and Appendix 6 presenting the factors and variables and their impact that currently influence the H_2 economy
- Figure 35 and 36 presenting conceptual models for designing business models for the H_2 economy
    - Figure 35 elucidates the overarching conceptual process on how business model designs are co-determined by input and output factors, emphasizing the systemic character of the processes
    - Figure 36 depicts the same process in greater detail and is populated with the study results
- Figure 37 and 39 then bring it all together and illustrate how the tables and the process concepts work together. The appropriate components can be selected from a number of elements and factors in order to design functional business models

To effectively utilize these conceptual tools, a pick-and-choose approach can be adopted. The following steps are a structured guide on how to use the tools:

1. **Understand the Elements, Factors and Variables:** Begin by familiarizing yourself with the diverse array of elements and influencing factors and variables offered in the above mentioned tables of the business meta-model. These elements form the building blocks for shaping your business logic.

2. **Identify Relevance and Applicability:** Assess the relevance, applicability and effectiveness of each element and influencing factor to your specific business context and objectives. Consider how each component can contribute to the development of a sustainable business model.

3. **Pick and Choose:** Select the elements and influencing factors that align most closely with your business goals and strategies and those being most effective. Adopt a pick-and-choose approach to tailor these components to suit your unique requirements.

4. **Compose Business Logic:** Use the selected elements to compose a coherent business logic that reflects your organization's values, vision, and operational framework. Ensure that this logic is aligned with sustainability principles and supports the creation of a robust business model.

5. **Iterate and Refine:** Continuously evaluate and refine your business logic based on feedback, performance metrics, and evolving market dynamics. Iterate on your model to enhance its effectiveness in driving sustainable practices and outcomes.

By following this user guide, practitioners can effectively harness the power of the business meta-model to develop innovative and sustainable business models within the hydrogen economy.

8.4. Limitations of the study

While quality criteria have been established in the design (Section 4.6), the study has several limitations, which are discussed in this section.

As a qualitative study, it is subject to the commonly discussed limitations of qualitative research, including generalisation, transferability, and representativeness of the results (Bryman & Bell, 2015; Gray, 2013; Saunders et al., 2019). The study was conducted as a case study on the German IPCEI projects, and data collection took place from January to August 2023. The primary data consists of a survey with approximately 30 participants, 16 semi-structured interviews with project actors and other stakeholders, several conference contributions, and recommended up-to-date reports serving as secondary data.

While certain findings may hold particular relevance for Germany, it is important to note that the majority of results gleaned from this study possess broader applicability within the European Union. The research has pinpointed EU legislation as a pivotal causal mechanism shaping business model designs and influencing key factors (as outlined in Table 8). However, it is worth acknowledging that there is a potential limitation concerning the transferability of these findings, stemming from the specific focus on the IPCEI projects as the case study. The rationale behind this selection is thoroughly detailed in Section 4.4. Nonetheless, it is argued that this choice does not significantly undermine the transferability of the results, given that the overarching conditions, drivers, and barriers for hydrogen projects remain consistent across contexts and are not contingent on the specific program. This perspective finds support among many of the interviewed stakeholders.

A common criticism of qualitative research is that the results are often based on relatively small numbers of participants (Bryman & Bell, 2015; Gray, 2013; Saunders et al., 2019). This criticism is rejected, as in addition to collecting primary data, several conferences with a comprehensive selection of top-class contributions have also been included. The 16 semi-structured interviews yielded a total of 702 minutes of recorded audio, which were transcribed. The interviews ranged from 19 to 80 minutes, with an average duration of 44 minutes. The conference contributions amounted to 425 minutes of audio and video material, and the reports summed up to 116 pages that also have been included. It is argued that this volume of data has allowed for a comprehensive understanding of the research topic to be captured.

The study is situated in the highly topical energy transformation field, where rapid changes are constantly occurring. Furthermore, the study has been conducted as a case study, and it is in the nature of case studies to examine contemporary phenomena within real-life contexts (Yin, 2018). The findings and results are time-sensitive and valid for the current conditions. However, their transferability into the future is considered to be limited, as it is anticipated that the H_2 economy will undergo significant maturation in the coming years.

The time-sensitive nature of the study could have been addressed by adopting an alternative research methodology, such as grounded theory. With this approach, one could have delved into the evolution of business model designs over recent years, potentially enabling to forecast potential future trends. However, it is crucial to acknowledge that while grounded theory offers valuable insights, it may also present its own set of limitations, particularly regarding the practical applicability of the findings.

The analyses in the study were conducted by the author, who has over 30 years of professional experience, including more than 10 years in hydrogen technology. However, only one researcher interpreted the data. This may have induced some subjectivity to the results. Key findings and results were presented to a few persons from the author’s professional network for a plausibility check, but this was not a systematic or auditable validation. This potential shortcoming could have been addressed by having multiple researchers conduct the analysis and triangulate the results or by involving an expert group in the process.

8.5. Areas for further research

In general, business models in a specific industry can be explored in different ways. One potential avenue, to analyse single products within the H_2 economy has been mentioned in Section 2.7. These different approaches and the highly exploratory nature of the study opens numerous opportunities for further research.

Two areas are particularly noteworthy. One pertains to topics that were of interest to participants and present in the data but fell beyond the scope of this study (see also grey shaded codes in NVIVO Codebook themes in Appendix 5). The other area involves topics that could not be fully explored in this study, thus providing promising starting points for future research.

Essentially, the study has drafted conceptual frameworks describing elements of the hydrogen system and their interactions. The study focussed on the value chain steps of hydrogen generation and transport (Figure 2). It was found that value chain integrated business models could be an interesting aspect for finding viable business models (refer to Section 7.3). Therefore, as an area for further research, it is suggested to explore the integration of business models for other steps in the value chain, such as renewable energy generation or the use of green hydrogen (refer to Figure 2).

Furthermore, it has been noted that the existing regulatory landscape and production expenses associated with green hydrogen pose obstacles to establishing a sustainable business model, especially when viability is narrowly framed within the confines of economic profitability. Recent trends have highlighted an increasing emphasis on sustainable and socially responsible business models (e.g., Bidmon & Knab, 2018; Galvão et al., 2020), broadening viability to encompass social and environmental advantages within the value creation process. Exploring these alternative perspectives on viability and their influence on business model formulation represents a promising direction for future research.

Other interesting aspects came up in the data but could not be further followed because they were out of the scope of the study. One of these aspects relates to the topics around imports of hydrogen and hydrogen derivatives. Many participants expressed concerns and hopes related to those import strategies. One participant (C9) said that using green hydrogen derivatives will generate new value chains. Exploring this area and the potential impact is suggested as a further research area.

Some findings of the study have not been analysed to the full extent. This applies, for example, to the interaction of the manifold causal relationships identified to be active in the H_2 system. In system theory, relationships and knowing WHY something is happening are assessed as the highest form of knowing.

Drawing from Section 7.4, a more in-depth study of the causal relationships and their mode of action could be rewarding. It could be valuable to explore the feedback loops and the influencing relations (see blue and pink arrows in Figure 41) in more depth.

Section 7.4 proposes this and suggests to use complex network theories, to be able also to investigate non-linear causalities.

This study endeavours to understand the complexity of business modelling within the H_2 economy system through qualitative analysis, resulting in rich narratives and informative maps. While the qualitative findings provide a solid foundation, there lies a vast opportunity for further exploration in transitioning from qualitative to quantitative understanding. Subsequent research could involve developing models that translate the qualitative insights gained in this study into quantitative representations. This may entail identifying mathematical formulas, determining percentage correlations among variables, or crafting descriptions that capture the essence of these relationships. Such quantitative models promise to facilitate scenario analysis, enabling the exploration of various potential futures. Organisations for example, could conduct scenario analyses by employing these models to assess the likelihood of different outcomes. This proactive approach could empower organisations to adapt their behaviour according to the most probable scenarios, thereby mitigating the impact of unfavourable developments. This adaptability spans across multiple domains, including technology, research and development, marketing, sales, and finance, among others.

As unpacked in Section 3.4, the central systemic idea is that it is the relationships between the parts rather than the parts themselves that cause the behaviour, and knowing WHY something is happening is the highest form of epistemological knowledge (Mingers, 2011, 2014). So, a deeper study into the interacting mechanisms of business model elements, influencing factors, and the wider environment and contextual circumstances using a complex system theory approach could further develop a holistic understanding of the H_2 economy system. This, again, could help politicians, economists, and managers take the right actions to facilitate its ramp-up. System theories, network theories, systems dynamics, and scenario analysis techniques offer such model approaches; similar work has been done by Cosenz and Noto (2018), Abdelkafi and Täuscher (2016), Moellers et al. (2017), Covarrubias, Kok.

8.6. Personal reflections

This chapter provides a personal reflection on this study's quality, meaning and purpose.

During the screening phase, it became apparent that business model designs for the IPCEI projects had not yet been developed. As a result, the aim of the study and the central research questions were slightly refined to align with the highly exploratory nature of the study. The refined aim was still to gather as much information as possible about business models for hydrogen projects but with a shift in focus towards investigating what business logic would enable the design of viable business models rather than scrutinising existing business models in the hydrogen economy. My reflections have delved into the following questions:

- Was the chosen approach, methodology and methods effective and efficient?
- Have the findings and results sufficient ground in the collected data? Are the analyses well done?

And last but not least:

- Was the study worth doing from a personal point of view?

In my opinion, this study provides deep insights into the current state and into the possibilities of building business models for the hydrogen economy. The potential composition of the business models has been thoroughly examined, including business model elements, influencing factors and causal mechanisms, and conceptual frameworks for the business meta-model and the current business design process have been developed. These findings have significantly enhanced my understanding of the "hydrogen system" while also highlighting the complexity of the system and the numerous tasks that remain open before viable business models can emerge on a larger scale. One surprising result for me was that, currently, the feasibility, i.e. the practical implementation and execution of the business model is even more important than its profitability. This means that actors must first ensure that the business model is feasible, i.e., check whether there is a customer, a supplier, a distribution channel, etc. Suppose there is no distribution channel, i.e. no transport option for the hydrogen. In that case, there is no need to think about the business's profitability simply because it is impossible to conduct the business.

I hope this study will also benefit others seeking to comprehend this highly innovative yet complex field.

The choice to embrace the philosophical tenets of critical realism and systems thinking has truly paid off. This approach has ushered in invaluable insights into the realms of stratified ontologies and open systems, enabling me to navigate complexity with a comprehensive outlook. Through this framework, I have come to appreciate that causality transcends mere linearity; instead, it is a nuanced interplay where a single effect can stem from various causes, and conversely, multiple effects can arise from a singular cause. This holistic perspective has greatly enriched my understanding and problem-solving capabilities.

My concerns about the data collection phase, particularly regarding acquiring suitable interview candidates, were unfounded. I was able to engage with many excellent interviewees, resulting in the collection of rich data from various sources, which formed a valuable pool for information and analysis.

However, the analysis proved to be challenging and time-consuming. I struggled with shaping the "story in my data" and determining what to include and exclude. For instance, although my data contained extensive information on the topic of importing

H_2 into the EU and Germany, along with its associated threats and opportunities, I decided not to include it in this study as it deviated from the main focus.

I am currently deliberating on my next steps regarding research. The study has unearthed numerous fascinating avenues warranting further exploration, many of which piqued my interest. One such area involves diving deeper into the causal network, focusing on refining and quantifying the causal relationships. I am considering employing a systems modelling approach to enhance this aspect of the research.

My research journey began in October 2020 and culminated in submitting this thesis in March 2024. It was a journey filled with challenges and rewards, but overall, it was very interesting and fulfilling. In addition to gaining knowledge about the subject matter and research tools, my most significant "aha moment" was learning about research paradigms and worldviews. Understanding positivist and constructionist stances and their epistemologies and ontologies that shape people's perspectives has significantly enhanced my understanding of how others behave in both my professional and personal life.

8.7. Concluding the study

The study has unveiled critical insights into business modelling for the hydrogen economy, providing a wealth of elements and parameters for designing innovative models. Furthermore, the study has pinpointed a range of influencing factors, categorized as input or output variables, that have significant impact on businesses. These factors, predominantly stemming from the macroeconomic environment and regulatory policies, are externally imposed, volatile, and subject to rapid change.

To thrive in this dynamic landscape, businesses must adeptly adapt to these external influences, remaining agile and flexible in shaping resilient business models. The development of conceptual models visually represents the current business logic, accompanied by a user guide demonstrating practical application. It has become evident that currently, only business models independent of H_2 infrastructure are deemed feasible (result of RQ3, Section 6.5.).

As businesses navigate this evolving terrain, it is imperative to integrate these findings into their strategic decision-making processes. The success of green H_2 projects is paramount in achieving the UN's Sustainable Development Goals and the EU's climate targets for climate neutrality by 2050. Despite ambitious goals, the ramp-up of the green H_2 economy is at a critical juncture. Recent reports from the Hydrogen Council and IEA reveal that only 4% of announced investments in H_2 projects are secured today. Contrary to predictions of cost reductions by at least 50% by 2050, recent trends show cost increases ranging from 30-65% in H_2 projects. By understanding the complexity of H_2 project business modelling, ensuring compatibility across the value chain, and staying adaptable to market dynamics, businesses can position themselves for success in the hydrogen economy while contributing to the crucial ramp-up of the H_2 economy essential for climate protection goals.

Future research should explore integrating business models across the value chain, broadening viability criteria to encompass social and environmental benefits, and leveraging complex system theories to uncover causal relationships quantitatively. Embracing these insights will not only drive innovation but also empower businesses to lead the charge towards a sustainable hydrogen economy.

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Appendices

Appendix 1 Systematic literature research (SLR) Research

The following table includes the SLRs that have informed the literature review about business models and business model innovation.

*due to space constraints in the table only the first author and year of publication is named

SLRs*	Scope	Purpose of SLR	Predominant method relevant for this study	Journal
General overviews over business model research				
Belussi, 2019	271 out of 3604 articles analysed, published between 1985-2017	General BM state-of-the-art overview and emergent fields	Quantitative by bibliometric analysis	Scandinavian Journal of Management
Cuc, 2019	500 out of 1509 articles analysed, published between 1994 and 2017	General BM state-of-the-art overview and emergent fields	Quantitative by bibliometric analysis	Business Models
Di Tullio, 2018	282 documents (+11 books)	General state-of-the-art overview and ontological and evolutionary aspects	Qualitative by identifying, history, definitions, components	Business Research and Management

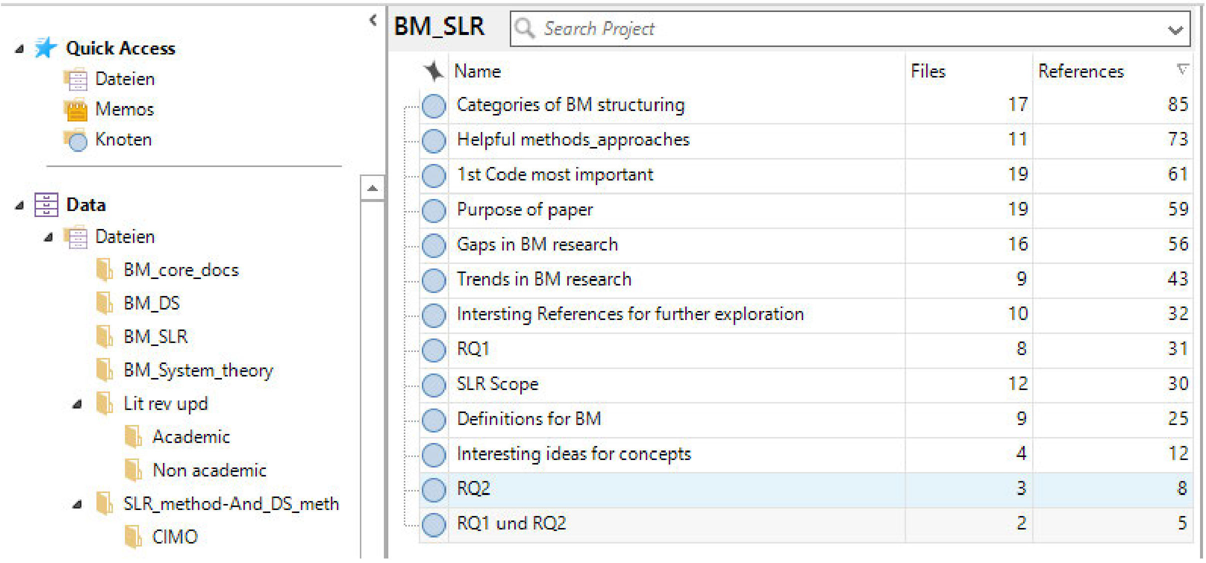
Musulin, 2018	?	BM concepts understanding and conceptualization	Qualitative concept structuring	Information and Organizational science
Täuscher, 2017	>150 graphical models of BM	General BM concept understanding	Qualitative by content and graphic form	Creativity and Innovation Management
Wirtz, 2016	681 peer reviewed articles	BM conceptualizations and heuristics	Qualitative	Long Range Planning
Business model innovation overviews				
Foss, 2017	150 articles, published between 200 and 2015	BMI , methods, research streams etc.	Qualitative	Management
Kraus, 2020	40 out of 287 articles analysed, published between 2016 and 2019	BMI state-of-the-art, key components of BMI	Qualitative by clustering the approaches to BMI and attributing dimensions to BMI	Innovation and Technology Management
Schaller, 2019	362 documents included in bibliometric analysis	Overview over BMI knowledge distribution (by geographic, location, time) and intellectual structure and trends	Quantitative by bibliometric analysis	Conference paper at PICMET'19

Wirtz, 2018	20 documents analysed, published between 2000 and 2014	Deep dive in BMI process; derive generic BMI process	Qualitative by identifying BMI processes	Business Models
Ramdani, 2019	Same as Wahyono, 2018	Same as Wahyono, 2018	Same as Wahyono, 2018	New England Journal of Entrepreneurship
Wahyono, 2018	219 papers analysed, published between 2010 and 2016	Advancements in BMI and to explore how firms approach BMI	Qualitative and quantitative	Indian Business Research
Daspit, 2017	156 documents analysed, published between 2001 and 2015	Overview over BMI literature	Qualitative by themes and perspectives in BMI research	Management & Governance
Specific business model subfield SLRs, relevant for investigated topic				
Centobelli, 2020	133 documents analysed out of 230, published between 2013 and 2018	BM for circular economy transition	Quantitative and qualitative by topic areas occurring in circular BMI	Business Strategy & the Environment
Galvao, 2020	44 documents analysed out of 194, published between 2007 and 2018	BM for circular economy	Qualitative by categories relevant for circular business model development	Resources, Conservation & Recycling

Geissdörfer, 2020	51 publications	Circular BM	Qualtitative content analysis for historical developments, clusters, definitions	Cleaner Production
Isensee, 2020	80 documents analysed out of 811, published between 2009 and 2019	Relationships of contextual factors (culture, digitalization) to BM in SMEs	Quantitative (relations between search strings) and qualitative by using the BAO framework	Cleaner Production
Jocevski, 2019	25 documents, publishes between 2000 and 2018	Interconnected BM	Quantitative and qualitative	Business & Industrial Marketing
Zhang, 2017	48 documents analysed out of of 1187, published between 1988 and 2016	Challenges of servitization business	Qualitative by analysing the seems an relationships between the themes	Industrial Marketing Management

<u>Systematic literature review: Codes for qualitative analysis (NVIVO)</u>

The following codes have been used for the qualitative content analysis (NVIVO):



The coding frames have been developed following the suggestions of Mayring and Fenzl (2014) and Kuckartz (2012), deductively from the research aim and the research questions and also inductively from the analysed articles to allow specifics to be included, which were not foreseen in the initial code creation.

Appendix 2 Questionnaire invitation, design and consent agreement

Survey invitation

Sehr geehrte Frau [redacted]

vielen Dank für das soeben geführte Telefonat und Ihre Bereitschaft an meiner Umfrage „Geschäftsmodelle für Wasserstoff-Großprojekte" im Rahmen meiner Doktor-Arbeit mitzuwirken.

Hier der Link zum Fragebogen: https://ww3.unipark.de/uc/gemmer-berkbilek_University_of_G/ce6e/

Gerne geben Sie diesen ans Projekt Team weiter. Wenn Sie einzelne Fragen nicht beantworten möchten, bitte einfach auslassen.

Zu meiner Person: Mein Name ist Kerstin Gemmer-Berkbilek, ich promoviere berufsbegleitend an der University of Gloucestershire im Bereich von Wasserstoff-Großprojekten. Der Fokus der Studie liegt auf den 62 H2-Projekten, die im Mai 2021 von der Bundesregierung zur IPCEI Förderung vorausgewählt wurden. Die Studie untersucht, welche Einflussfaktoren in der künftigen Wasserstoffwirtschaft relevant sind und wie Geschäftsmodelle optimiert werden können.

Ihre Erfahrungen und Einschätzungen als Akteur in einem der IPCEI-H2-Projekte sind für diese Studie essentiell. Deshalb bitte ich Sie, meine Forschung zu unterstützen und sich ca. 10-15 Minuten für die Beantwortung des Fragebogens Zeit zu nehmen.
Die Umfrage ist anonym und dient rein wissenschaftlichen Zwecken.
Gerne sende ich Ihnen nach Abschluss der Umfrage die anonymisierte Auswertung zu. Dazu genügt eine kurze Antwort auf diese Mail.

Nochmals herzlichen Dank

Kerstin Gemmer-Berkbilek
PhD Candidate und Researcher
University of Gloucestershire
Tel. [redacted]

Questionnaire design

1 Willkommensseite

Dear participant,

Thank you for taking part in the survey. This questionnaire is aimed at stakeholders in all German IPCEI projects (see logo) and other large hydrogen projects. It comprises ***five subject areas*** *with questions that are mainly to be answered in multiple-choice mode. Please mark the answer or answers that apply to your project. For some questions you will also find free text fields, please use these for additional information, additional information is particularly valuable for the depth of the investigation. The questionnaire takes about* ***10-15 minutes*** *to complete.*

And now have fun with the survey!

2 Products&Services

A) Your hydrogen project: products & services

Which products are produced in your project?

Please mark and complete if necessary in the free text field (multiple selection possible).

☐ H2

☐ O2

☐ Heat

☐ synthetic fuels (e.g. kerosene, methanol)

☐ electrolysers

☐ fuel cells

☐ Other, e.g.

Which services are offered in your project?

Please mark and complete in the free text field (multiple selection possible).

- ☐ H2 distribution (e.g. pipeline transport)
- ☐ H2 storage (e.g. cavern)
- ☐ H2 mobility (e.g. public transport, heavy traffic)
- ☐ H2 use for industries (e.g. steel, chemicals, refineries)
- ☐ O2 use for industry (e.g. cement, waste water treatment)
- ☐ (green) electricity generation (e.g. PPAs)
- ☐ local or district heating supply
- ☐ Other, e.g.

3 Projektstatus

B) Your IPCEI project: project progress

How satisfied are you with the progress of the project?

Please position the slider to the position that best suits your satisfaction.

absolutely dissatisfied	dissatisfied	neutral or no information	satisfied	extremely satisfied

You are welcome to explain why you are satisfied or dissatisfied.

Please use the following text box for this purpose

How do you assess the progress of the project development?

The 62 IPCEI projects were preselected by the federal government in May 2021. Other important project milestones are usually the final investment decision and the start of commercial operation. Please estimate where your project is between these milestones and move the slider to the appropriate position.

When is your project expected to go into commercial operation?

Please select the date that seems realistic to you from today's perspective.

4 Drivers&Barriers

C) Your hydrogen (IPCEI) Project: drivers & barriers

In your opinion: What are the 3 most important drivers for your project's business model at the moment?

Please rank the currently most important drivers for your project from the list below by clicking. (Clicking again deactivates the selection made and you can rank again).

- **positive business plan**
- **grant approval is available**
- **further investment commitments are available**
- **low interest on borrowed capital**
- **management support**
- **building permits are available**
- **clear regulatory framework**
- **increasing market demand for green hydrogen**
- **purchase agreements with customers are in place**
- **H2 technologies are ready for the market**
- **fixed partnerships with technology suppliers are in place**

Is there anything else beyond the drivers mentioned above that would currently boost your project?

If so, use the text box below for a brief description.

In your opinion: what are currently the 3 biggest barriers to your project's business model?

Please rank the currently most important drivers for your project from the list below by clicking. (Clicking again deactivates the selection made and you can rank again).

- no positive business plan
- pending funding commitment
- lack of further finance for invest
- unclear regulatory framework
- adverse regulatory framework
- lengthy approval processes
- no market demand
- too low market prices for green H2
- Lack of human resources
- H2 technologies not mature
- business activities blocked by patents
- competition with other, national H2 projects
- lack of public acceptance for the projects
- competition with other, international H2 projects (import H2)

Beyond the above barriers, is there anything else that would seriously jeopardize your project?

If so, use the text box below for a brief description.

5 Aktueller Kontext

D) large hydrogen projects in the context of current politics

In your opinion: How important are the following contextual topics for the implementation and realization of large hydrogen projects?

Please select your assessment for each topic and complete it if necessary.

	rather unimportant	neutral or no information	important	very important
The climate goals of the EU	○	○	○	○
The H2 strategies and roadmaps formulated by Germany and the EU	○	○	○	○
The public acceptance for H2 projects and technologies	○	○	○	○
The technical maturity of the new technologies and products (e.g. electrolysers, H2 vehicles, etc.)	○	○	○	○
The (still high) costs of the new technologies and products (e.g. electrolysers, H2 vehicles, etc.)	○	○	○	○
The need to develop new technologies (e.g. DRI, methanol synthesis)	○	○	○	○
Other contextual issues, e.g.	○	○	○	○

The EU and national governments have launched a number of funding initiatives and activities to promote hydrogen as an energy carrier.
In your opinion, how effective are the following measures for the market ramp-up of the hydrogen economy?

Please select your assessment for each topic.

	rather unimportant	neutral or no information	important	very important
aid for the construction of plants and projects (= CAPEX Funding)	○	○	○	○
aid for the operation of plants and projects (=OPEX Funding)	○	○	○	○
funding for university research and development of H2 technologies	○	○	○	○
feedstock quota for green H2 for different applications	○	○	○	○
CO2 emission pricing	○	○	○	○
double auction model	○	○	○	○
Carbon Contracts for Difference (CCfD)	○	○	○	○
simplification and standardization of regulatory requirements	○	○	○	○
Communication and educational campaigns for the public	○	○	○	○

How effective do you think the IPCEI project application process is in driving the ramp-up of hydrogen technologies in Europe?

Please select the appropriate one and complete if necessary.

- ◯ not effective
- ◯ effective, but can still be improved, e.g.
- ◯ very effective
- ◯ no information

The following list contains the most important national laws and regulations that need to be adapted or changed for the production, transport and use of hydrogen.
Which of these are relevant to your project?

Please select and complete if necessary.

	not relevant	relevant	no information
Erneuerbare-Energien-Gesetz (EEG 2021)	◯	◯	◯
Vergabe von sonstigen Energiegewinnungsbereichen in der ausschließlichen Wirtschaftszone (SoEnergieV)	◯	◯	◯
Energiewirtschaftsgesetzes (EnWG)	◯	◯	◯
Wasserstoffnetzentgeltverordnung – WasserstoffNEV	◯	◯	◯
Bundes-Immissionsschutzgesetzes (BImSchG) (Umsetzung EU REDII) und 37. Bundesimmissionsschutzverordnung	◯	◯	◯
EU-Clean Vehicles Directive (Richtlinie (EU) 2019/1161)	◯	◯	◯
Beschaffung sauberer Straßenfahrzeuge (SaubFahrzeugBeschG)	◯	◯	◯
Aufbau der Infrastruktur für alternative Kraftstoffe (RL 2014/94/EU-Alternative Fuels Infrastructure Directive – AFID)	◯	◯	◯
Windenergie-auf-See-Gesetz (WindSeeG)	◯	◯	◯
Alternative Fuels Infrastructure Regulation – AFIR	◯	◯	◯
Andere Verordnungen sind relevant, z.B.	◯	◯	◯

6 Statistische Angaben und Abschluß

What is your role in the project?

Please select one or more roles or describe your role. (The answer will only be evaluated for statistical purposes).

- ☐ Project manager
- ☐ Communicationsmanager / presse contact
- ☐ CEO
- ☐ other role

Which category does your project belong to?

Please select the appropriate icon. (The answer will only be evaluated for statistical purposes).

H2 generation	Infrastructure	Use for industries	Use for mobility
H2 generation	Infrastructure	Use for industries	Use for mobility

If your project does not receive IPCEI funding, will the project still be continued (e.g. with national funding)?

- ○ yes
- ○ no
- ○ that is not decided yet

Are there other aspects that could be important for successful business models of large-scale hydrogen projects?

Please use the following text area for your additional information, notes and comments.

7 Endseite

Thank you for your participation!

I will be happy to send you the anonymous evaluation after the survey has been completed. If you are interested in the report, please send me a message to [redacted]

Liebe/r Teilnehmer/in,

vielen Dank für Ihr Interesse an einem Expertengespräch zum Thema Geschäftsmodelle für Wasserstoff-Großprojekte teilzunehmen. Mein Name ist Kerstin Gemmer-Berkbilek, in meiner Doktorarbeit untersuche ich die Geschäftsmodelle der 62 Projekte, die im Mai 2021 von der Bundesregierung zur IPCEI Förderung ausgewählt wurden (Pressemeldung 28.05.2021).

Die Studie ist als qualitative Fallstudie angelegt. Sie hat zum Ziel herauszuarbeiten welche Einflussfaktoren in der künftigen Wasserstoffwirtschaft relevant sind und wie Geschäftsmodelle optimiert werden können.

Ihre Erfahrungen und Einschätzungen als Stakeholder und Akteur im Themenfeld großskalige Wasserstoff Projekte sind für diese Studie daher essentiell. Die Teilnahme umfasst ein Expertengespräch, online oder persönlich, mit Aufzeichnung und anschließender anonymisierter Transkription. Die anonymisierten Transkripte werden durch qualitative Inhaltsanalyse ausgewertet.

Informationen zur Datenverarbeitung

Im Rahmen dieser Studie werden keine personenbezogenen Daten, sondern nur personenbeziehbare Daten, wie z.B. Rolle im Projekt und Einschätzungen zu den Projekten erhoben. Die Daten werden nur zum Zwecke der Forschung erhoben. Die Forschung folgt keinem kommerziellen Interesse. Alle Daten werden streng vertraulich behandelt und nur anonymisiert weiterverarbeitet und veröffentlicht. Eine Zuordnung der Daten zu einer Person, einem Projekt oder einem Unternehmen ist ausgeschlossen.

Veröffentlichungen der anonymisierten Ergebnisse und Analysen sind im Rahmen der Doktorarbeit geplant, und gegebenenfalls in Auszügen auch als Publikation in Fachjournalen und Fachkonferenzen.

Freiwilligkeit und Daten Aufbewahrungsdauer

Die Teilnahme an der Studie ist freiwillig. Sie können die Befragung jederzeit abbrechen. Die Daten werden nach Fertigstellung der Doktorarbeit gelöscht.

Ich stimme zu, dass meine Daten gemäß den hier aufgeführten Datenschutzbestimmungen verarbeitet werden.

____

Datum, Unterschrift

UNIVERSITY OF GLOUCESTERSHIRE
at Cheltenham and Gloucester

Expertengespräche

"Geschäftsmodelle für Wasserstoff – Großprojekte"

Treiber & Barrieren

- Welche Treiber befördern die Projektumsetzung?
- Welche Barrieren behindern die Projektumsetzung?
- Gibt es noch andere beeinflussende Faktoren?

Akteure im zukünftigen Geschäftsmodell „Wasserstoff"

- Wer sind die künftig wichtigsten Akteure?
- Gibt es neue Akteure?
- Welche Rolle wird der Staat spielen?

Förderinstrumentarien & IPCEI Prozess

- Welche Förderinstrumentarien sind wirksam?
- Welche Förderinstrumentarien sind weniger wirksam?
- Wie wirksam ist die IPCEI Förderung?

„Wasserstoffwirtschaft 2030"

- Wie sieht die Wasserstoffwirtschaft in 2030 aus?
  - Wer ist beteiligt?
  - Wer verdient etwas dran?
- Wie sieht der Import von Wasserstoff aus?

Kerstin Gemmer-Berkbilek, +[redacted] Doktorand und Researcher; [redacted]

Appendix 3 Survey Report complete

Final Report 1 English

Autor	Kerstin Gemmer-Berkbilek
Datum der Generierung	16. 10. 2023 (18:09)

Report-Informationen

UMFRAGEBESCHREIBUNG

-ohne Admin Sprachenänderung

BEGINN DER UMFRAGE	31. 12. 2022 (00:00)
ENDE DER UMFRAGE	31. 10. 2023 (00:00)
GESAMTSAMPLE	75
NETTOBETEILIGUNG	30
UMFRAGE BEENDET (CODE 31 ,32, 33, 34)	24

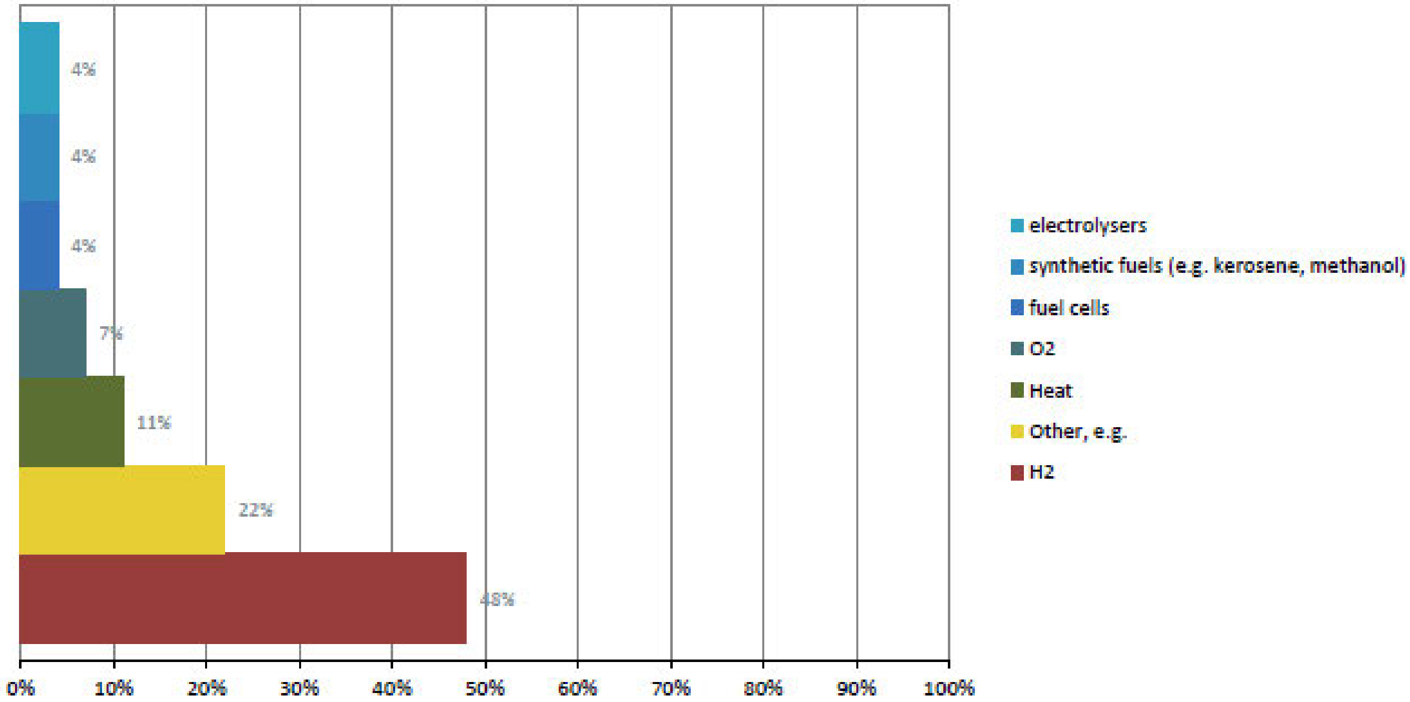
Inhaltsverzeichnis

01. Products & Services

MEHRFACHAUSWAHL UNTEREINANDER - PRODUKTE

Which products are produced in your project?

REPORTFILTER (27)



01. Products & Services

MEHRFACHAUSWAHL UNTEREINANDER - PRODUKTE - OTHER, E.G.

Which products are produced in your project? - Other, e.g.

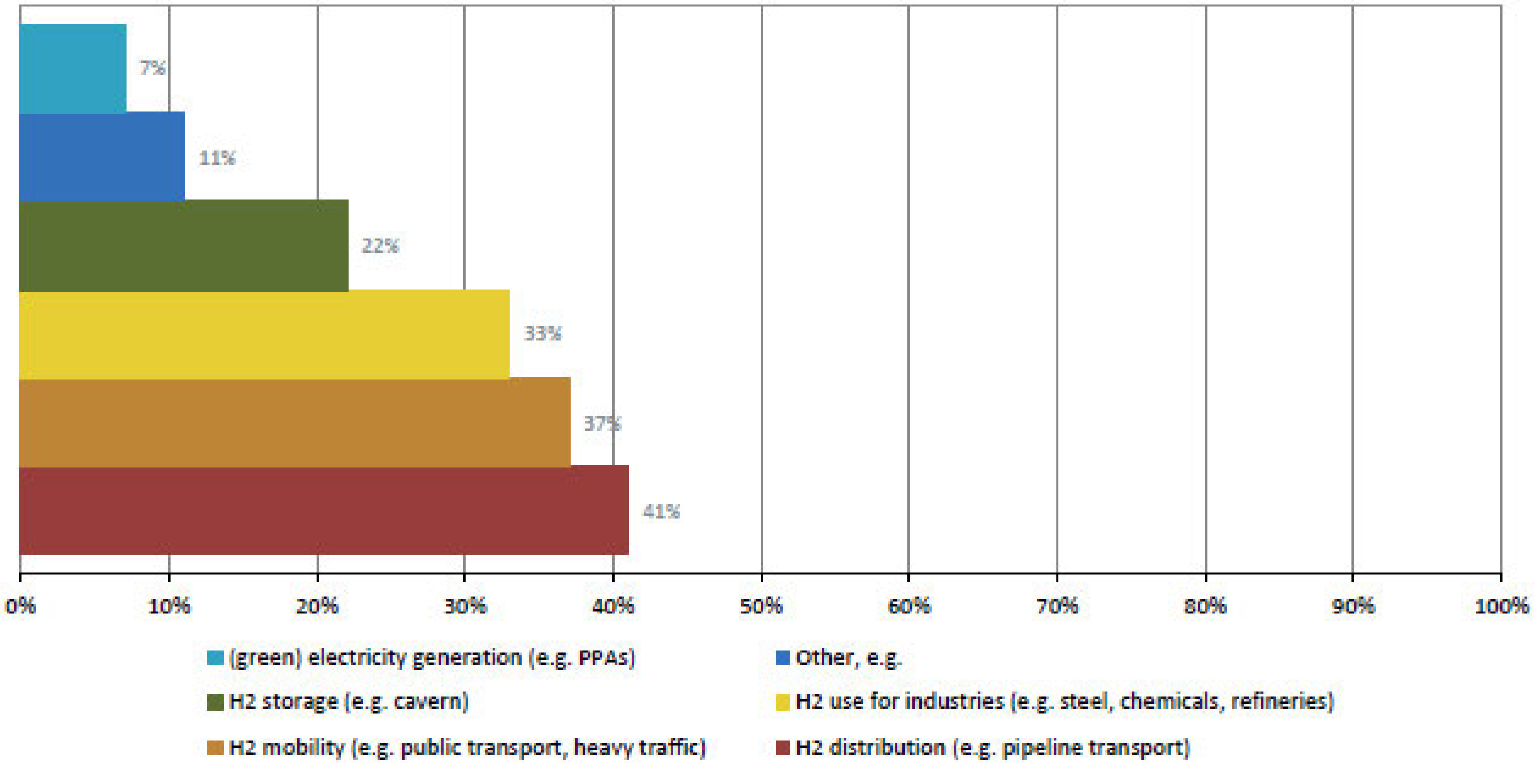
REPORTFILTER (30)

ANTWORTOPTION
Services
Pipelines / Breitstellung von Infrastruktur
Nur H2 Logistik, also Leitungsbetrieb
Im Prinzip gibt es Möglichkeiten, alle PRodukte, also auch O2 und H2 zu verwenden
es wird noch untersucht, ob O2 oder Wärme verwendet werden kann

01. Products & Services

Multiple Selection- SERVICES (N=27)

Which services are offered in your project?



01.

Products & Services

MEHRFACHAUSWAHL UNTEREINANDER - SERVICES - OTHER, E.G.

Which services are offered in your project? - Other, e.g.

REPORTFILTER (30)

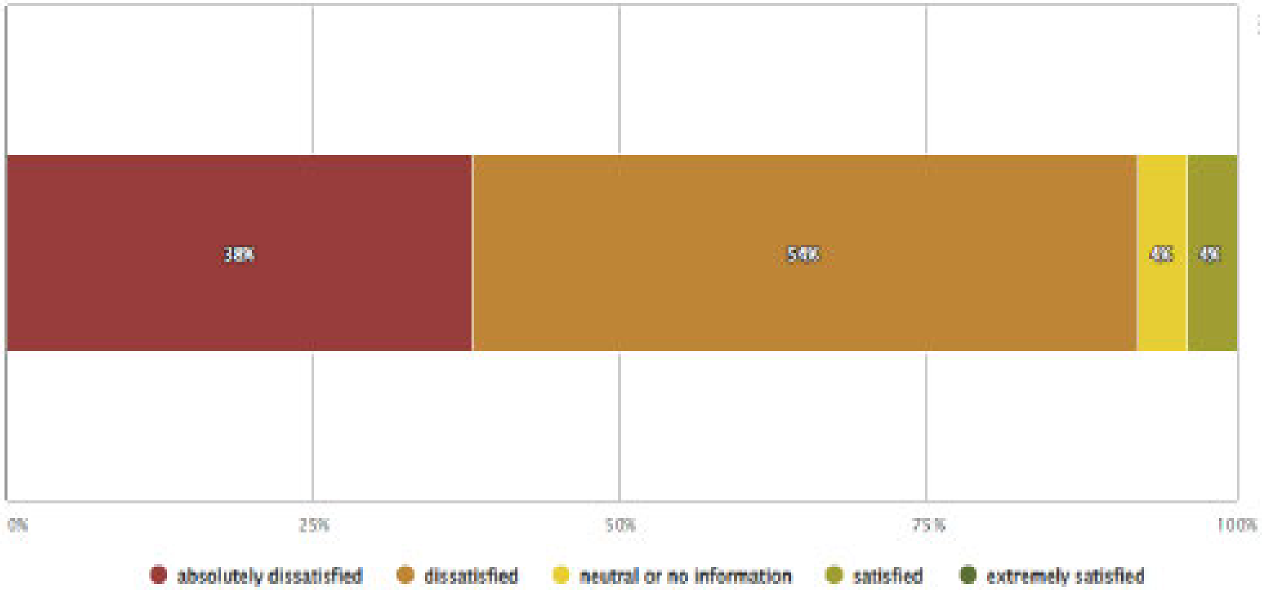
ANTWORTOPTION
Nutzung für Brennstoffzellen
Hauptteil geht in die Raffinerie
Consulting & Business Model Development

Inhaltsverzeichnis

02. Project status

SLIDER SATISFACTION PROJECTPROGRESS (N=26)

How satisfied are you with the progress of the project?



02. Project status

TEXTBEREICH ZUFRIEDENHEIT

You are welcome to explain why you are satisfied or dissatisfied.

REPORTFILTER (30)

ANTWORTOPTION
Aufwändige Verfahren um Fördergelder (von denen nur wenig passende Programme verfügbar) zu bekommen Pläne liegen "in der Schublade" können aber aufgrund mangelnder finanzieller Unterstützung nicht umgesetzt werden
Kein Projektfortschritt, Entscheidung über Bewilligung erfolgt frühestens in der zweiten Jahreshälfte 2023.
Fahrzeuge und Betankungsinfrastruktur werden im Rahmen von IPCEI nicht gefördert
schwierige Rahmenbedingungm durch poplitisch bedingte Entscheidungsunfähigkeit
Positiv: Hohes Engagement aller Beteiligten in Bund und Ländern. Attraktive Fördermittelhöhe. Negativ: Lange Bearbeitungsdauer von Ideenwettbewerb bis Zuwendungsbescheid. Begrenzter Förderzeitraum.
Die Förderungsthematik ist sehr enttäuschend. Die IPCEI Notifizierung dauert sehr lange, noch hat kein Projekt aus der 3.Welle Förderung erhalten. Die Notifizierung wird dauernd verschoben, soll jetzt Ende 2023 sein oder erst Anfang 2024.
es könnte schneller gehen
IPCEI Prozess könnte schneller gehen - wir warten auf Notifizierung
könnte schneller gehen; IPCEI Prozess ist kompliziert und IPCEI Prozesse in unterschiedlichen Ländern sind unterschiedlich
Alle H2 Projekte entwickeln sich langsam, weil auf der regulatorischen Seite wirklich noch viel zu regeln ist und sich vorher eigentlich keine H2 Wirtschaft entwickeln kann.
langwieriger Prozess, IPCEI Förderung ist für Akteure nicht planbar
Zu lange Bearbeitungszeiten bei der EU

02. Project status

TEXTBEREICH ZUFRIEDENHEIT

You are welcome to explain why you are satisfied or dissatisfied.

REPORTFILTER (30)

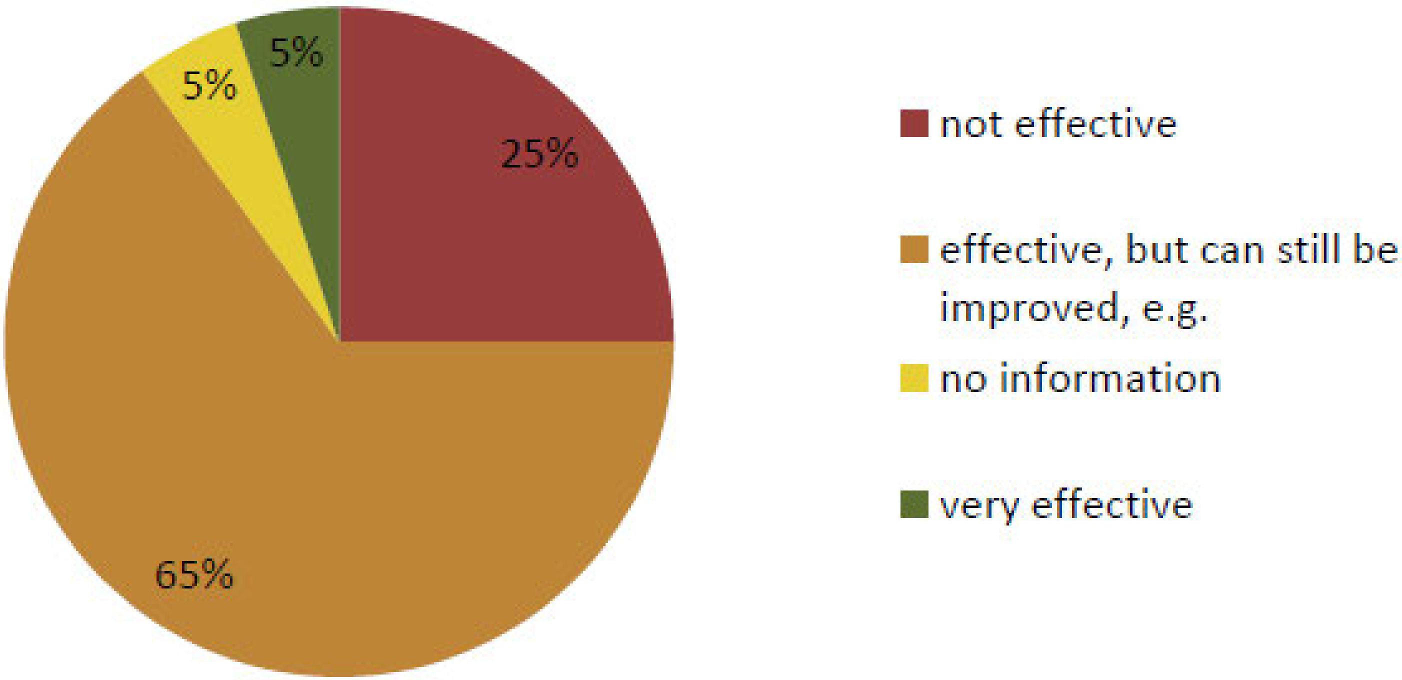
ANTWORTOPTION
Notifizierungen auf EU Ebene haben >1 Jahr Verspätung
Es werden generell mit den H2 Markt-Versprechungen große Hoffnungen geweckt, die evtl. nicht erfüllt werden so schnell --> Rückschläge und Enttäuschungen sind möglich. Cluster Förderung, wie in IPCEI ist sinnvoll.
Förderung / IPCEI Notifizierung dauert zu lange
Beantragung in Form und Umfang viel zu lang, viel zu träge Rückantworten (Bearbeitungszeit > 1 Jahr)
viele Dinge sind nicht geregelt bis jetzt

02. Project status

EINFACHAUSWAHL UNTEREINANDER EFFEKTIVITÄT IPCEI

How effective do you think the IPCEI project application process is in driving the ramp-up of hydrogen technologies in Europe?

REPORTFILTER (25)



EFS ANALYTICS 12

02. Project status

EINFACHAUSWAHL UNTEREINANDER EFFEKTIVITÄT IPCEI - WIRKSAM, ABER KANN NOCH VERBESSERT WERDEN, Z.B. DURCH

How effective do you think the IPCEI project application process is in driving the ramp-up of hydrogen technologies in Europe? -

REPORTFILTER (30)

ANTWORTOPTION
deutlich weniger Komplexität
schneller machen
schnellerer Prozess
schneller und weniger formalistisch
Vereinheitlichung der Prozesse in verschiedenen europäischen Ländern
Beschleunigung des Antragsverfahrens
schneller
schneller, einfacher machen
muss ergänzt werden durch andere Fördermassnahmen,

02. Project status

SCHIEBEREGLER PROJEKTFORTSCHRITT-1

How do you assess the progress of the project development? (answer option)

REPORTFILTER (30)

How do you assess the progress of the project development?

The 62 IPCEI projects were preselected by the federal government in May 2021. Other important project milestones are usually the final investment decision and the start of commercial operation. Please estimate where your project is between these milestones and move the slider to the appropriate position.

Project selection (May 2021) | final investment decision | start of commercial operation

50 %

02. Project status

SCHIEBEREGLER PROJEKTFORTSCHRITT-1

How do you assess the progress of the project development? (answer option)

REPORTFILTER (30)

ANTWORTOPTION
37
35
31
29
29
26
25
25
25
21
16
12

	37	
	35	
	31	
	29	
	29	
	26	
	25	
	25	
	25	
	21	
	16	
	12	
	11	
	10	
	10	
Summe	342	22,8

Scale according to questionaire:
- 0-20% Project Selection Mai 2021
- 40-60% FID
- 80-100% COD

Average 22,8%

02. Project status

SCHIEBEREGLER PROJEKTFORTSCHRITT-1

How do you assess the progress of the project development? (answer option)

All below 40%, therefore nobody had FID

REPORTFILTER (30)

ANTWORTOPTION
11
10
10
-77
-77
-77
-77

Scale according to questionaire:
- 0-20% Project Selection Mai 2021
- 40-60% FID
- 80-100% COD

EFS ANALYTICS 15

02. Project status

DATUMSAUSWAHL COD-1

When is your project expected to go into commercial operation? (date field)

No, because dates are not very informative as none of the projects has had FID yet

REPORTFILTER (30)

ANTWORTOPTION
2025-02-07
2025-06-01
2025-12-31
2026-01-01
2026-12-31
2026-12-31
2026-12-31
2026-12-31
2026-12-31
2027-01-01
2027-12-30
2028-12-31

02. Project status

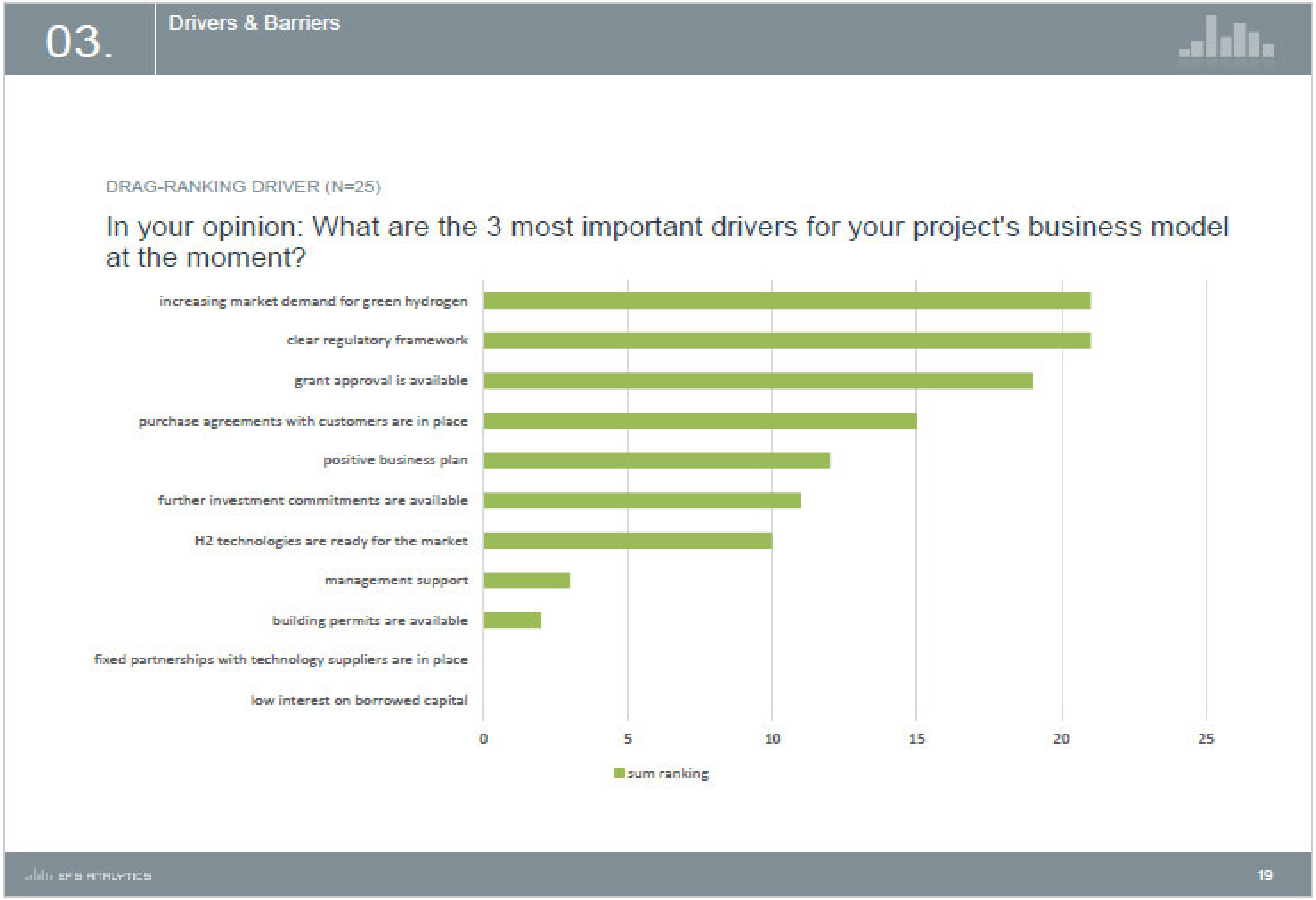
DATUMSAUSWAHL COD-1

When is your project expected to go into commercial operation? (date field)

REPORTFILTER (30)

ANTWORTOPTION
2028-12-31

Inhaltsverzeichnis


03.
Drivers & Barriers
DRAG-RANKING DRIVER (N=25)
In your opinion: What are the 3 most important drivers for your project's business model at the moment?
increasing market demand for green hydrogen
clear regulatory framework
grant approval is available
purchase agreements with customers are in place
positive business plan
further investment commitments are available
H2 technologies are ready for the market
management support
building permits are available
fixed partnerships with technology suppliers are in place
low interest on borrowed capital
0
5
10
15
20
25
sum ranking
19

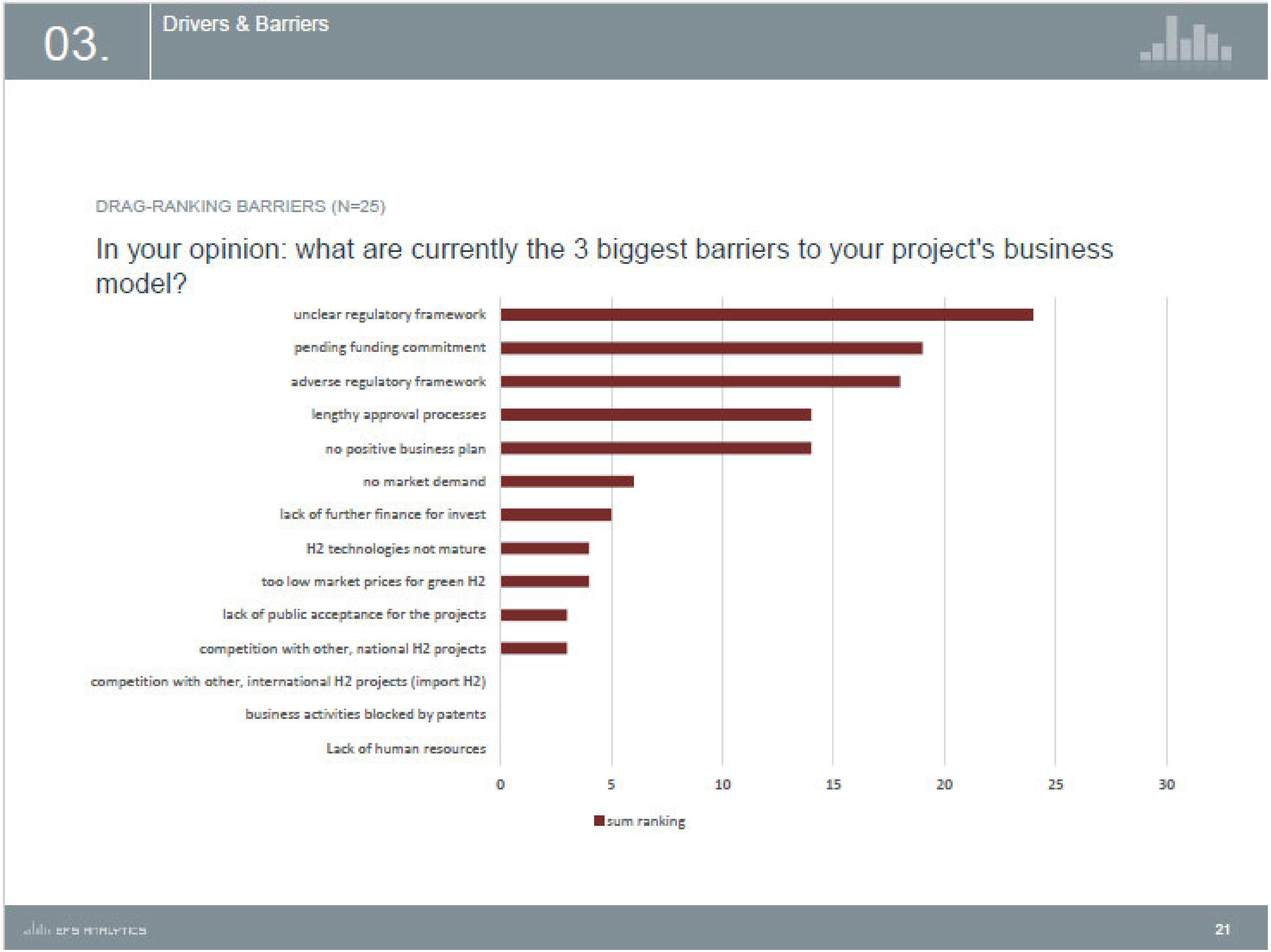
03. Drivers & Barriers

TEXTBEREICH BOOSTER

Is there anything else beyond the drivers mentioned above that would currently boost your project?

REPORTFILTER (30)

ANTWORTOPTION
Wasserstoffanwendungen bei schweren schwere Fahrzeugen, insbesondere Schiffen und Lokomotiven müsste gefördert werden.
Schnellerer Förderprozess
CO2 intensive Industrien (Zement, Stahl) müssen umsteigen
jeder will was mit grünen Wasserstoff machen - das Thema ist envogue
hauptsächlich treibt die Nachfrage im Stahl Bereich (DRI)
Anreize für Sektorkopplung und Flexibilitätsvermarktung müsste angereizt werden - hier könnte viel mehr getan werden
Die Unternehmen haben Lust auf grünen Wasserstoff Nachhaltigkeitsgedanken
Größter Treiber ist die H2 Strategie der EU (Fit for 55, CfD etc.)
3,5 - 4€/kg für grünen H2 wäre attraktiv. Eine Lieferkette über Import und Nachfrage muss aufgebaut werden. Feed-In Tarife (ähnlich wie beim Grünstrom) wären interessant.
Notifizierung müsste durch sein
Na ja, es sind viele Unternehmen (z.B. Stahlindustrie) Standort gebunden
feste Regeln / Regulatorik, feste Planbarkeit des Invests


03.
Drivers & Barriers
DRAG-RANKING BARRIERS (N=25)
In your opinion: what are currently the 3 biggest barriers to your project's business model?
unclear regulatory framework
pending funding commitment
adverse regulatory framework
lengthy approval processes
no positive business plan
no market demand
lack of further finance for invest
H2 technologies not mature
too low market prices for green H2
lack of public acceptance for the projects
competition with other, national H2 projects
competition with other, international H2 projects (import H2)
business activities blocked by patents
Lack of human resources
0
5
10
15
20
25
30
sum ranking
EFS ANALYTICS
21

03. Drivers & Barriers

TEXTBEREICH BARRIERS

Beyond the above barriers, is there anything else that would seriously jeopardize your project?

REPORTFILTER (30)

ANTWORTOPTION
Völlig Lebensfremdheit, übertriebene kleinteilige Formalität und Verfahrensdauer für die zu betreibenden Verfahren (Notifizierung, Nationale Verfahren etc.)
Keine Förderung
fehlende passende Rahmenbedingungen, man braucht zumindest die Grundnachfrage nach H2, sonst kriegt man keine Infrastruktur ausgebaut
Henne - Ei - Problem
Frischwasser ausreichend in südlichen Ländern?, und der Einfluss von H2 Anwendung auf die Endanwender (Umstellung der Prozesse)
Netzanschlüsse für grüne Energieerzeugung fehlt. Unklare Umstellungsaufwände für manche Endnutzer (zB Stahlindustrie)
zu wenig grüner Strom ist vorhanden
Langsame EU Bearbeitungsprozesse
Mit IPCEI Förderung kann kein planbarer Business Plan erstellt werden. Subsidies wie IRA ziehen mehr private Investoren an, weil besser planbar. In D, A, CH fehlt generell der grüne Strom für die H2 Vorhaben
Wenn Regulierung innerhalb dieses Jahres nicht kommt, dann passiert das gleiche wie bei PV und Wind - die Technologie wandert ab.

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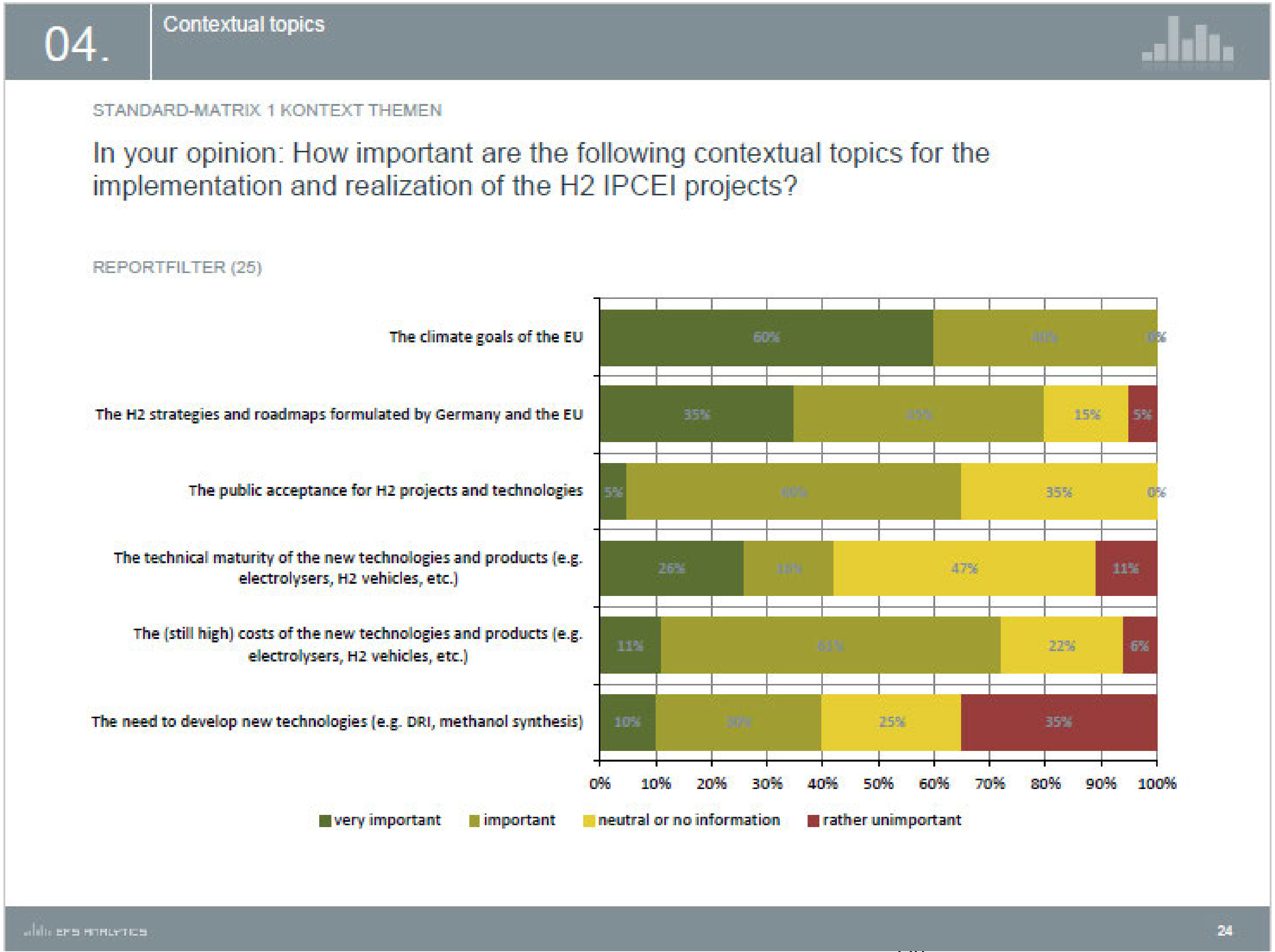

04.
Contextual topics
STANDARD-MATRIX 1 KONTEXT THEMEN
In your opinion: How important are the following contextual topics for the implementation and realization of the H2 IPCEI projects?
REPORTFILTER (25)
The climate goals of the EU
60%
The H2 strategies and roadmaps formulated by Germany and the EU
35%
15%
5%
The public acceptance for H2 projects and technologies
5%
35%
0%
The technical maturity of the new technologies and products (e.g. electrolysers, H2 vehicles, etc.)
26%
47%
11%
The (still high) costs of the new technologies and products (e.g. electrolysers, H2 vehicles, etc.)
11%
22%
6%
The need to develop new technologies (e.g. DRI, methanol synthesis)
10%
25%
35%
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
very important
important
neutral or no information
rather unimportant
24

04. Contextual topics

STANDARD-MATRIX 1 KONTEXT THEMEN - OTHER CONTEXTUAL ISSUES, E.G.

In your opinion: How important are the following contextual topics for the implementation and realization of the H2 IPCEI projects? - Other contextual issues, e.g.

REPORTFILTER (30)

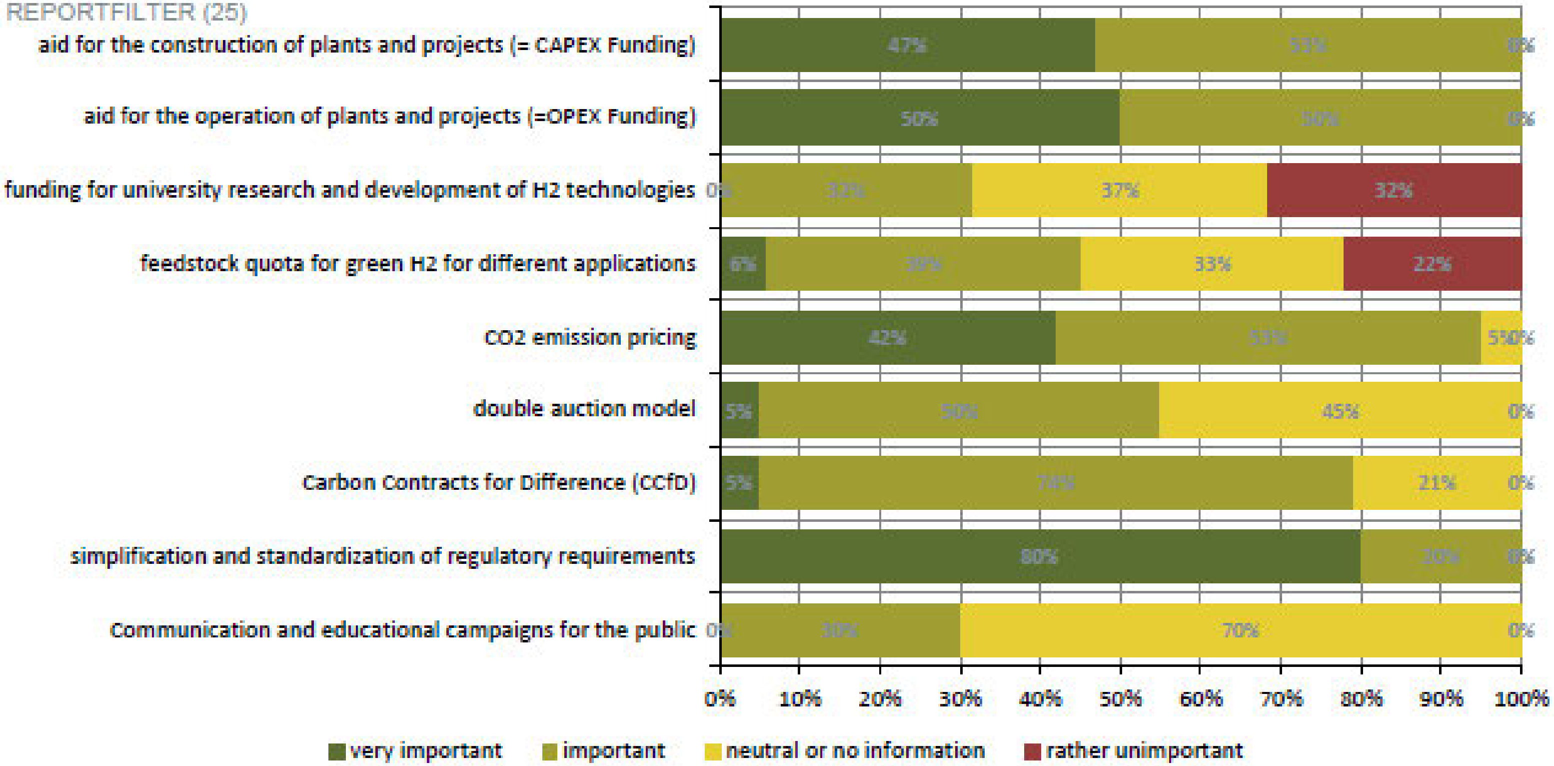
ANTWORTOPTION
die Klimaverträge

04. Contextual topics

STANDARD-MATRIX 1 FUNDING PROGRAMME

The EU and national governments have launched a number of funding initiatives and activities to promote hydrogen as an energy carrier. In your opinion, how effective are the following measures for the market ramp-up of the hydrogen economy?

REPORTFILTER (25)

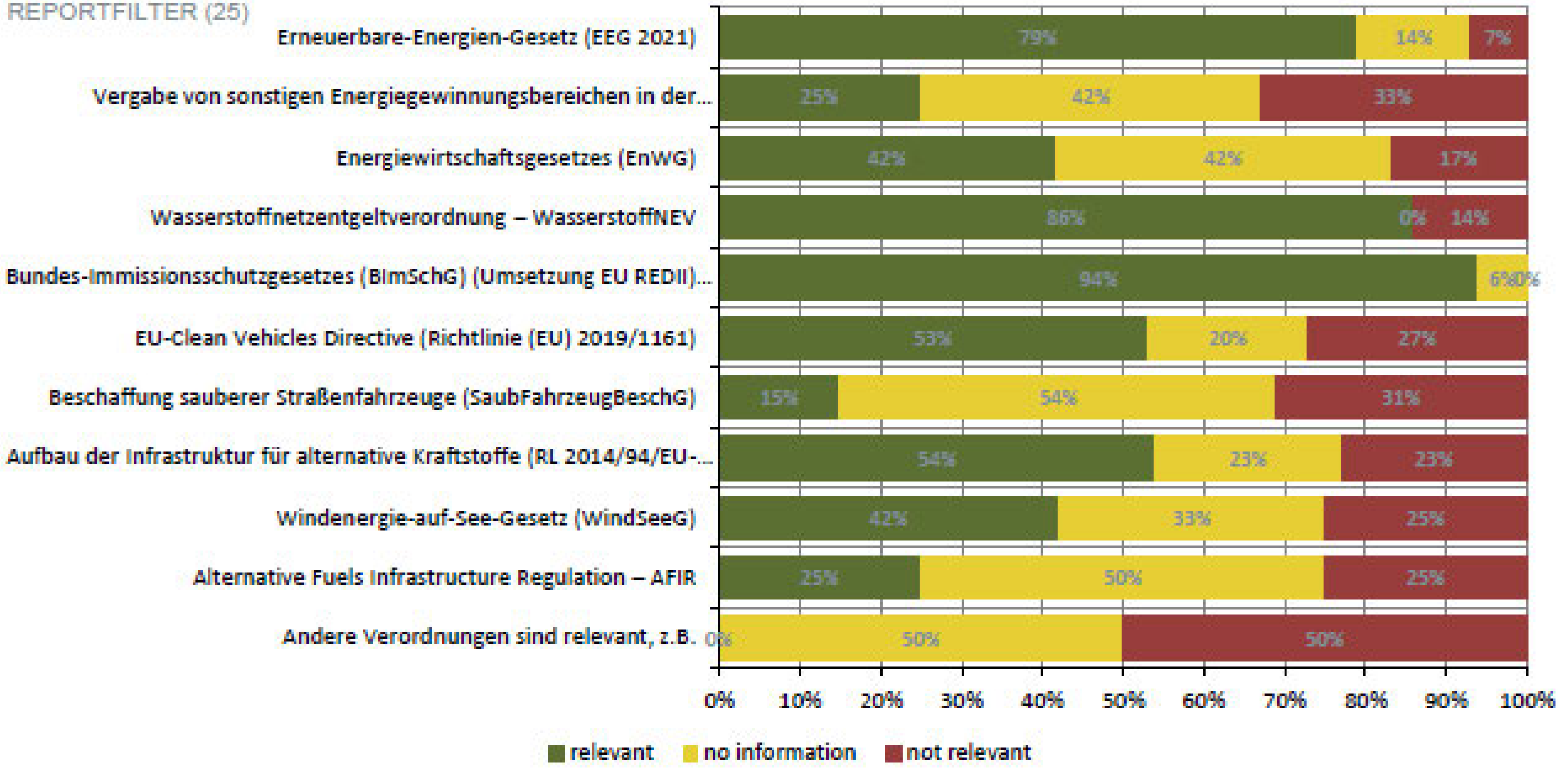


04. Contextual topics

STANDARD-MATRIX 1 REGULATORY FRAMEWORK

The following list contains the most important national laws and regulations that need to be adapted or changed for the production, transport and use of hydrogen. Which of these are relevant to your project?

REPORTFILTER (25)



04. Contextual topics

STANDARD-MATRIX 1 REGULATORY FRAMEWORK - ANDERE VERORDNUNGEN SIND RELEVANT, Z.B.

The following list contains the most important national laws and regulationsthat need to be adapted or changed for the production, transport and use of hydrogen. Which of these are relevant to your project? - Andere Verordnungen sind relevant, z.B.

ANTWORTOPTION
Clusterförderung von H2 Clustern ist sehr effizient
CO2 Preise

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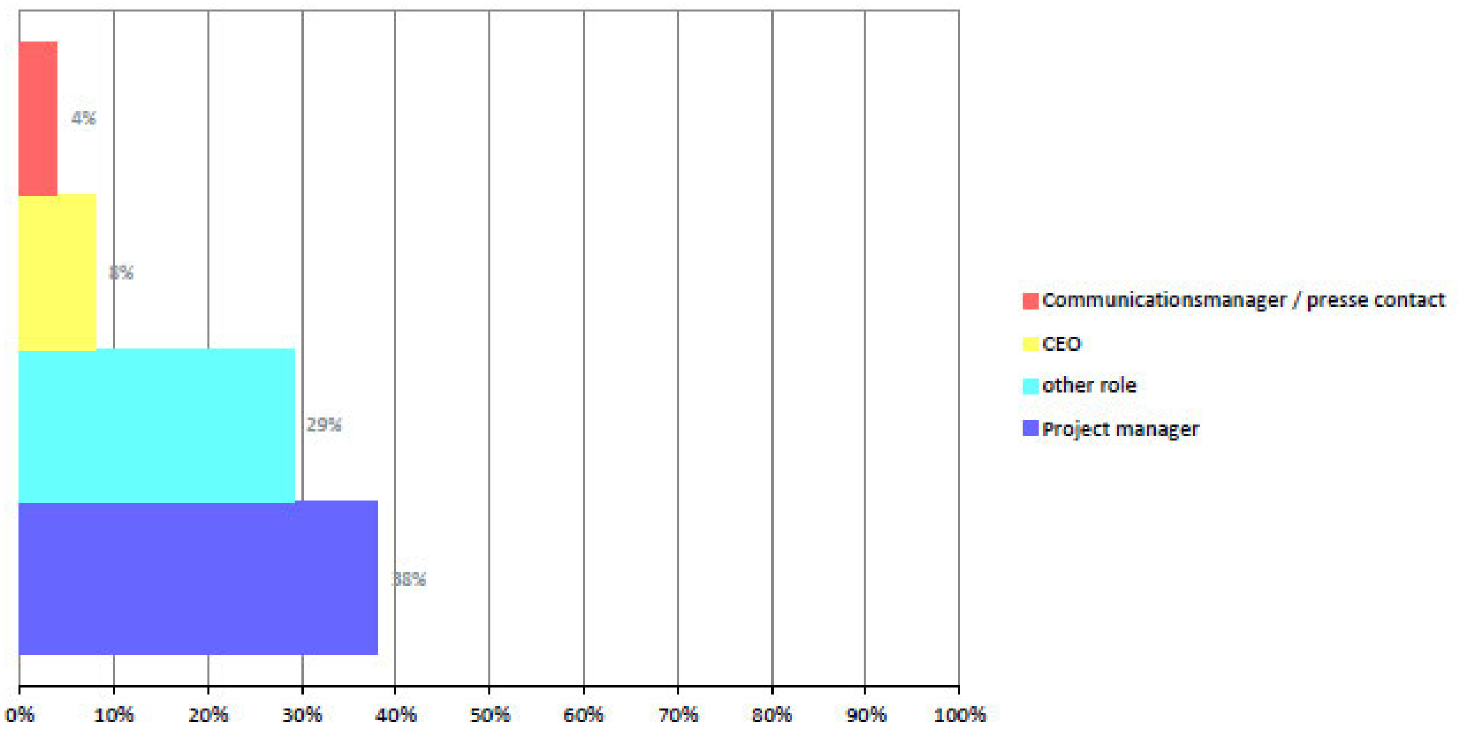
05. Statistics and conclusion

ROLLE IM PROJEKT

What is your role in the project?

REPORTFILTER (24)



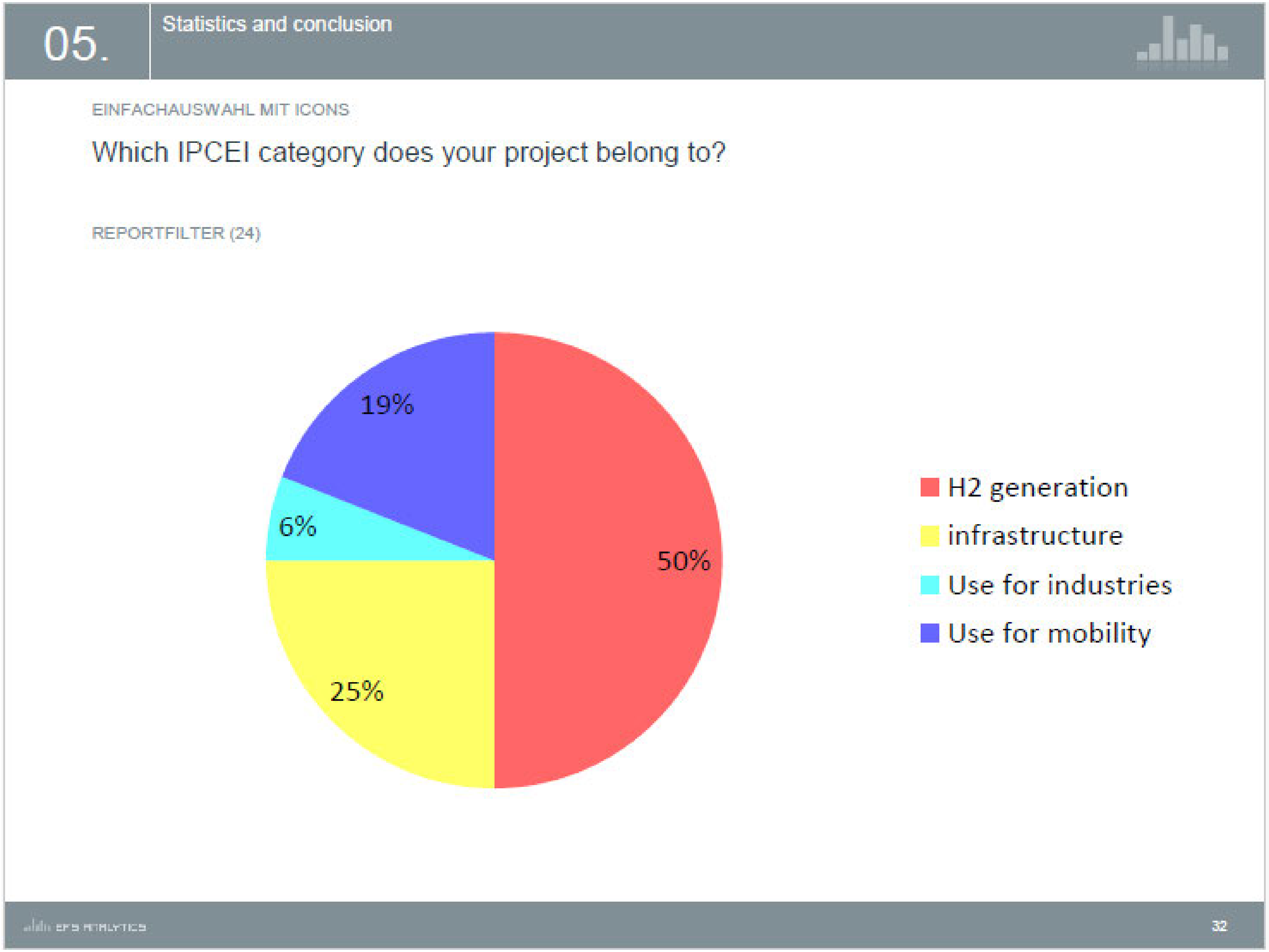
05. Statistics and conclusion

ROLLE IM PROJEKT - OTHER ROLE

What is your role in the project? - other role

REPORTFILTER (30)

ANTWORTOPTION
Forschung
Business Development
Consultant
Akademia
Consultant, BM Developer
Interessenverband Vertreter
Investor

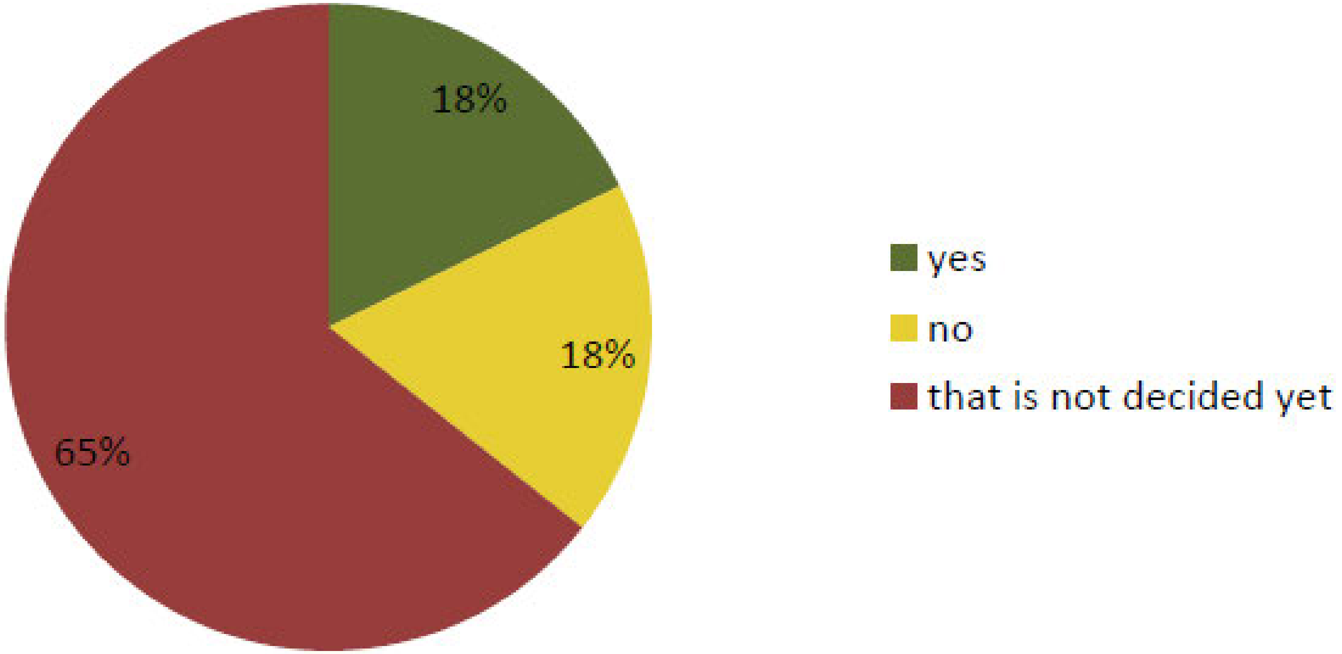

05.
Statistics and conclusion
EINFACHAUSWAHL MIT ICONS
Which IPCEI category does your project belong to?
REPORTFILTER (24)
19%
6%
50%
25%
H2 generation
infrastructure
Use for industries
Use for mobility
32

05. Statistics and conclusion

EINFACHAUSWAHL NEBENEINANDER IPCEI FUNDING JA NEIN

If your project does not receive IPCEI funding, will the project still be continued (e.g. with national funding)?

REPORTFILTER (24)



05. Statistics and conclusion

TEXTBEREICH - SCHLUSSSTATEMENT

Are there other aspects that could be important for successful business models of large-scale hydrogen projects?

REPORTFILTER (30)

ANTWORTOPTION
THG Quotenhandel für H2 im Transportsektor ermöglichen. Mit den Projekten mal anzufangen, wäre auch nicht schlecht.
Wenn die Förderung eingestellt wird, gibt es keine H2 Produktion in Deutschland. Und man wird wieder vom Ausland abhängig.
Das verstärkte UNabhängigkeitsbestreben der EU von außereuropäischen Energiequellen
Sektorenkopplung und Felxibilitätsvermarktung sollte regulatorisch angereizt werden
Geopolitisceh Aspekte für den Import Wasserstoff
Import H2, Ammoniak Transport , synth.MEthan sehen wir zuerst von außerhalb, weil Struktur schon vorhanden ist.
Genug Grünstrom, funktionierende Infrastruktur
ppa
sinnvoll kombinierte Förderinstrumentarien

Appendix 4 Overviews datasets main phase (interviews, conference contributions)

Overviews interviews – primary data collection

Participant ID	Category	Focus Topic	Role	Type of interview	When	Duration (min)
I1	Project	H2 Generation	Project Manager	MSTeams	May 22, 2023	25
I2	Project	H2 Logistic	Project Manager	MSTeams	May 16, 2023	25
I3	Project	H2 Logistic	Project Manager	MSTeams	April 26, 2023	58
I4	Project	H2 Generation	Project Manager	MSTeams	April 04, 2023	19
I5	Project	H2 Generation	Project Manager	MSTeams	April 14, 2023	80
I6	Project	H2 Logistic	Business Developer	Face to Face	April 26, 2023	70
I7	Project	H2 Generation, Logistic, M	Strategy Manager	Telephone, no audio, notes during telephone call - in screening phase	Feb 10, 2023	25
I8	Academia	BM H2	Researcher	MSTeams	May 05, 2023	43
I9	Academia	Funding Models	Researcher	MSTeams	April 13, 2023	59
I10	Association	IPCEI Process	Project Manager	MSTeams no audio, r	Feb 22, 2023	80
I11	Consultant	Funding Models	Sales Manager	Face to Face talk - no audio, notes during talk + memory protokoll	Mar 28, 2023	30
I12	Consultant	Investments, new BMs	Consultant	MSTeams	May 8, 2023	34
I13	Consultant	Voices from stakeholders	Academic employee	MSTeams	May 12, 2023	50
I14	Consultant	Hydrogen Bank	Consultant	MSTeams	May 31, 2023	25
I15	Politician	Political influence on topi	H2 expert of government	MSTeams	Aug 16, 2023	34
I16	Association	required initiatives	Chairman Association	MSTeams	May 26, 2023	45

Overviews conferences – secondary data collection

Participant ID	Category	Focus Topic	Role	Type of data	When	Duration (min) / (pages)
C1	Academia	Strategy and Macroeconomic	Economic expert	Speech	Apr 26, 2023	30
C2	Association	H2 Strategies	Chairman Association	Speech	May 10, 2023	30
C3	Finance	Financing	Financial expert	Speech	May 24, 2023	30
C4	Academia	Strategy	Researcher	Speech	May 24, 2023	30
C5	Association	H2 Infrastructure	Chairman Association	Speech	June 14, 2023	30
C6	Association	European H2 roadmap	Chairman Association	Speech	June 6, 2023	20
C7	Panel	Decarbonizing Industry	diverse industrial represe	Panel	June 6, 2023	40
C8	Project	H2 Projects	CEO	Speech	June 7, 2023	15
C9	Panel	The role of ports	diverse industrial represe	Panel	June 7, 2023	45
C10	Association	H2 Forecast	Chairman Association	Speech	June 7, 2023	15
C11	Association	H2 Forecast	Chairman Association	Presentation	June 7, 2023	20
C12	Company	European H2 Backbone	Industrial expert	Presentation	June 7, 2023	20
C13	Company	H2 Mobility	Industrial expert	Presentation	June 7, 2023	20
C14	Company	H2 Project	Industrial expert	Presentation	March 27/28, 2023	20
C15	Company	H2 Project	Project Manager	Presentation	March 27/28, 2023	20
C16	Company	H2 Mobility	CEO	Presentation	March 27/28, 2023	20
C17	Company	Incomes from H2	Financial expert	Presentation	March 27/28, 2023	20
D1	Project	IPCEI Funding	Company presentation	Doc		2 pages
D2	Finance	Financing	Report	Doc		31 pages
D3	Academia	TRANS4REAL	Report	Doc		70 pages
D4	Finance	Climate investing...	Report	Doc		12 pages
D5	Project	H2 Project	Company presentation	Doc		1 page

Appendix 5 Codebook NVIVO Themes (Export December 14, 2023)

Codebook Export from NVIVO: NVIVO project name: Data analysis themes.nvp

The following table shows the exported codebook from NVIVO, including file and reference numbers. The codes that have not been included in the data analysis (Chapter 6) are shown just for information at the end of the tables.

Name	Description	Files	Codes
BUSINESS MODEL ELEMENTS_RQ i)	**1) What elements are the business models consisting of?**	**36**	**605**
INVESTMENT FINANCE GOVERNANCE (theme 1)	Everything that belongs to project finance, investment decision and information that is related to governance in this context	27	187
Info and pros and cons about funding instruments	Information given about funding instruments, what is helpful, what is not helpful	17	60
IPCEI process and IPCEI funding	Information given about the IPCEI process and how the IPCEI funding works	18	51
Which assets are in business models	Information on who owns or co-owns which asset. For example, who owns the gasgrid, who owns the electrolysers.	7	9
Which governance structures are in business models	What type of business structure is selected (GmbH, JV etc)? Information about who takes influence on government and steering of the businesses.	13	26

Name	Description	Files	Codes
Who invests and finances	Information about who could potentially invest and finance the projects	13	41
ACTORS & MARKETS (theme 2)	Information about markets and players on the markets	29	166
Actors already involved in BMs	Information about parties already being active in various ways and roles in H_2 economy.	5	8
Information about masses, quota and media	Information about market sizes or demands in different industries.	13	27
New upcoming actors	Information about new companies in new roles that are entering the energy field.	13	29
Old actors with new roles, new BMs	Information about incumbent companies that take over new roles or design new business models	11	29
who are customers and markets	Information about potential customers and markets. Also information about which industires are likely to become markets in future.	17	64
Who are suppliers	Information about suppliers of electrolysers or other equipment needed for H_2 economy.	4	9
TECHNOLOGY & INFRASTRUCTURE (theme 3)	Technology topics, also technical maturity, technical information about trasnport, H_2 logistic and also storage of H_2	21	149

Name	Description	Files	Codes
Electrolyser fabrication issues and planning	Information about potential ramp-up capacities for electrolyser manufacturing, also so-called giga factories	12	23
Maturity of technologies & products	Information about technological readiness of technologies and products	11	40
Storages	Information about H_2 storage, also caverns, piplines, LOHCs.	7	20
Transport and H_2 logistics	Information about the transport and logisitcs of H_2, also includes H_2 derivates.	16	66
VALUE (theme 4)	Everything that is related to value	24	103
what are the product and services	Information about products in the business model and services that are planned to be offered	17	39
what is the source of value creation in the BM	Information about what can be sold in the project, how to generate revenue. Also in a broader sense, also grid servies etc.	15	49
which activities are performed in the business	Information about what activities are planned in the business or before the business is founded, what is to be done, what could be done.	8	15
INTERACTING MECHANISMS, INFLUENCING FACTORS_RQ ii)	**2) How are those elements interacting? influencing factors, mechanisms, power / Influencers external? Internal?**	**36**	**429**

Name	Description	Files	Codes
POLICIES & REGULATORY (theme 5)	Which policies and regulatorie are discussed currently that influence the ramp-up	32	219
Colours of H_2 and related certification topics	Information about how H_2 is categorizrd in various colours and what this means for certification and how certification is related to funding.	10	23
Influence of (German) government	Information about which influence the German government takes on business model creation and on market creation and also other governments, e.g.EU.	13	31
Info and pros and cons about funding instruments	This code has been allocated to theme 1 and theme 5, as funding plays an important role.	17	60
IRA and EEG Set up and comparisons	Information about the US funding mechanism IRA in comparison to the European funding settings. And also what was said about the German EEG in comparison.	13	43
what policies and actions do we see in creating BMs	Information about what activities is the state, the government taking. Which activities influence the business model.	25	62
OBSTRUCTIONS (theme 6)	What hinders the ramp-up of the H_2 economy	25	107
CAPEX OPEX Costs, Interest rates	Information about in how far lack of money hinders H_2 economy ramp-up.	12	25

Name	Description	Files	Codes
Changed contexte - War, energy, crisis, inflation	Information about how the inflation and the influences of the war (Ukrainian) negatively impacts the H_2 ramp-up.	10	13
long lead times for project approvals etc.	Information about in how far lengthy project development times and permission processes hinder the H_2 economy ramp-up	12	17
overselling	Many promises have been made related to H_2 and economy and economical progress and timelines. Many of these promises maybe cannot be kept, which can hinder the ramp-up.	3	5
regulatory and or political framework	Information in how far regulatories and political framework is hindering the H_2 economy ramp-up.	18	47
MOTIVATORS (theme 7)	What helps the ramp-up of the H_2 economy	29	103
Enough renewable energy	Having enough green electricity most likely means that it is cheap and that could be a strong driver for realizing the projects	1	1
funding and_or finance secured	Information about how secured finance and funding is a driver for the project implementation	6	9
Hype general motivation for H_2	H_2 is a fancy topic, also at management levels. H_2 projects are hype.	9	15

Name	Description	Files	Codes
Independency in topics of energy supply	Since Russian war and related gas supply reductions, Europe and Germany strives for diversification of energy supply and for independency in energy supply. All that was said regarding these topics is in tis code.	10	15
regulatory and political framework	Information in how far regulatories and political framework is boosting the H_2 economy ramp-up.	17	33
Security of H_2 supply, dependencies	Information about how H_2 supply can be secured, e.g. for industries thta have changed their processes	6	10
THG quote and decarbonization, gas prices	Information about Green House Gas Emissions and other directives to reduce CO_2, also information about gas prices and gas sector	13	20
BUSINESS MODEL DESIGNS_RQ iii)	**3) What business model designs are considered today for upcoming large scale green hydrogen projects?**	**29**	**161**
BM 2030 (theme 8)	Which business model designs do the participants consider to become viable in 2030	20	68
Future of oil industry and energy generation industry, needs in industries	How do the future scenarios for various industries and their obligations and needs drive the H_2 ramp up	15	38

Name	Description	Files	Codes
Pic of the future	Participants where asked, how the business models in 2030 for H_2 projects might look like	16	30
BM CAUSALITIES (theme 9)	What causal relationships are active in the business model designs?	18	59
Constellations of supplier and customer favourable or unfavourable	Things and relations that were explained about supplier and customers that are favourable	12	25
Explanation of not viable or viable Business model	Information about business models that might come close to viability or not and the reasons for that	12	25
General value chain thoughts and descriptions	Information given about the complete value chain from renewable energy generation over H_2 generation to H_2 transport, storage and usage	5	9
BM INTERIM (theme 10)	Which business model designs could become viable although there is not a liquid market yet?	13	34
Cluster H_2 business model-respect H_2 hub	How do or could "Cluster H_2" business models, "Local Hub" business models look like	10	15
Grid and pipeline business models	How in concrete could H_2 grid or pipeline business models be composed	9	19
Not used for data analysis:			
Memorable Quotes		27	77

Name	Description	Files	Codes
Risks, threats and other disadvantages for Europe and Germany		15	62
Deindustrialization Europe-Germany	Information about general economic risks when H_2 economy is not developing well in Europe and Germany	12	34
Not enough green electricity or energy in general	The expansion of the renewable electricity generation is too slow (windmills, solar) and therefore there is by far not enough green electricity for all the electrification that is planned	9	21
War, inflation, energy crisis as risk in general	Information about how these topics could impact the economy, more in general	4	7
Import H_2		21	89
Challenges related to import H_2	What is difficult about import H_2, difficult for German / European industry etc., also technical issues and geopolitical issues	17	46
Chances related to import H_2	What could be good for Germany and Europe, when importing H_2, what could also be good for the H_2 exporting countries	17	43
(IPCEI) project info (timelines and content)	All concrete information about the history, status and timeline of the IPCEI projects	19	90

Appendix 6 Detailed Summary: Findings for Interacting Mechanisms, Influencing Factors

The table presented below contains the relevant driving forces and correlations; the original formulations of the participants (translated into English) have been retained as far as possible. Following the perspective of critical realism (Bhaskar et al., 2017; Mingers, 2014), the interacting mechanisms were categorised into three levels showing the underlying causalities (the REAL), the Factors and Frames (the ACTUAL) produced by the underlying causalities and the Indicators and Impact (the EMPIRICAL)) that are provoked by the factors and frames when applying them. The indicators and impacts can be observed and perceived in the business.

The table, e.g. line 1 reads like this: The EU legislation with its various policies brings about various regulations, such as quota obligations for emission reductions, that have an impact on the value for green H_2 and create (indirectly) a market for H_2 and raises willingness to pay for green H_2.

The cells are shaded in alternating colours to make the categorization easier to read. The cells with a green background in the table indicate the causal relationships that are triggered by the EU. The cells with a white background indicate those triggered by national government actions and green again indicate macroeconomic influences. The bold table entries indicate the topics that the participants mentioned particularly frequently and as particularly relevant.

Underlying causalities (the REAL)	Factors and Frames (the ACTUAL)	Indicators and Impacts (the EMPIRICAL)
EU Legislation, various policies e.g.: • EU Goals (Net Zero) • EU Climate policy • EU Green Deal (2019)	**Quota obligations** for emission reduction, e.g.: • RED II, RED III • E Fuel directive Funding frames, e.g.: • IPCEI, Innovation Fund, European Hydrogen Bank	raises value for green H_2; creates market for H_2, however indirectly (i.e. after translating it to national laws) Raises value (i.e. willingness to pay) for green H_2 complements national funding programs; improves economics of business model; reduces levelized costs for H_2 produced; raises appetite for investment
	EU Taxonomy obligation (i.e. to do sustainable investments)	directs investments towards green investment and therefore raises appetite for investment into H_2 projects and undertakings
Processes and administration burdens	**Timelines** for project development	influences **risk for projects**; influences project costs; influences EU /Germany's position in global competition and is a threat for migration of industry
EU and national objectives to **reduce dependency** on energy imports	Domestic H_2 production	increases willingness to invest in local H_2 production; increases security of H_2 supply; increases urgency to act and to accelerate the ramp-up of H_2 economy
	Diversifying technologies	increases openness for H_2 generation paths; increases openness for H_2 import paths;

Underlying causalities (the REAL)	Factors and Frames (the ACTUAL)	Indicators and Impacts (the EMPIRICAL)
(National) Government Market Design (such as carbon pricing)	CO_2 **price**, e.g. • CO_2 certificate price • CO_2 tax	increases price for the use of fossil energies and therefore makes green H_2 more attractive; improve economics of business model
	CCfDs (Carbon Contracts for Difference), e.g.: • for products • for energy carriers	incentivizes CO_2 intensive industries (steel, chemicals, cement, ceramics, glass) to decarbonize; creates **demand for** H_2; creates a market for H_2; facilitates coordination of supply and demand; reduces risk for projects
	gas grid transformation plan	Enable fair and socially balanced access to green H_2 grid; creates market for H_2
(National) Government Mandates (such as emissions reductions)	CO_2 Emissions Zero in 2050, creating specific regulations for certain sectors, e.g.: • GEG (Building Energy Act) • CVD (Clean Vehicle Directive)	Creates demand for H_2; creates applications for H_2 and therefore creates possibilities to learn about the technologies; creates a market for H_2
(National) Government subsidies (such as investment or production tax credits)	**CAPEX funds** (e.g. IPCEI, Reallabore etc.) **OPEX funds** (e.g. feed-in tariff, subsidised electricity prices, H_2 Global etc.)	improves economics of business model; reduces levelized **costs for** H_2 produced; raises appetite for investment
Macroeconomics	• Inflation rate • Electricity price	influences the levelized costs for H_2 produced and the economics of the business model; influences EU /Germany's position in global competition, threats industry to migrate