Analyzing and addressing value conflicts in the adoption of hazardous chemicals in the energy transition

A methodological exploration of combining systems thinking and value-driven methods in the design of energy systems

Master Thesis MOT

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Analyzing and addressing value conflicts in the adoption of hazardous chemicals in the energy transition

A methodological exploration of combining systems thinking and value-driven methods in the design of energy systems

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Executive Summary

The energy transition requires the adoption of various hazardous chemicals to generate, transport and utilize energy. In this adoption process, value conflicts between stakeholders need to be considered to foster the social acceptance of these chemical molecules. To be able to anticipate on these value conflicts, this study aimed to develop and evaluate a methodological framework for analyzing and addressing value conflicts in the adoption of hazardous chemicals in the energy transition. By integrating principles from systems engineering and value-driven design methods, as well as input from experts in both fields, a framework was developed. The developed methodological framework consisted of three steps being: 1) Applying Systems Thinking to define the socio-technical system the chemical is adopted in and conceptualize stakeholder values (conceptual investigation), 2) Identifying values and value conflicts (empirical investigation) and 3) Classifying and addressing value conflicts (technical investigation). This approach innovates upon the default tripartite value-sensitive design approach by incorporating Systems Thinking in the conceptual investigation phase to suit the broader context of socio-technical systems design rather than just the design of physical technological artifacts like wind turbines and nuclear reactors. Furthermore, it combines parts of existing VSD frameworks in the empirical and technical investigation phase in a novel way.

The methodological framework was evaluated by conducting a case study on the adoption process of ammonia in the Dutch energy transition. To inform the empirical investigation, 11 expert interviews with policy advisors, industry players and research experts provided in-depth information about the values and value conflicts at play. However, it was noted that the broad nature of the interview questions limited the ability to derive specific technical design requirements, suggesting that future studies should adapt the interview questions to focus on particular parts of the socio-technical system if desired. In the empirical investigation phase, value hierarchies were constructed from the value level to the norm level, which provided useful for identifying value conflicts.

The results of the empirical investigation revealed seven major values which play a role in the adoption process of ammonia in the Dutch energy transition being: efficiency (of both spatial planning and the energy transition in general), competitiveness, cooperation, safety and health, environmental sustainability, transparency, and (procedural and distributive) justice. The values identified in this study were found to be comparable with those found in related works on the adoption of technologies like nuclear energy and wind turbines. Seven value conflicts were identified by comparing the norms related to each value and the framework was used to address and classify them. This allowed to derive policy implications.

There is a need for more transparent communication with the public about the energy transition, available technology alternatives to reach net-zero, the associated risks of those alternatives, and the ethical dilemmas that the government is facing. It was established that local communities are willing to bear risks if the government clearly states what the ethical dilemmas are in the energy transition and the choices made in these dilemmas. This vision can build social acceptance from the industry and local communities and address the identified value conflicts between safety and health, justice, and efficiency. In this vision, the government should also address their standpoint on the ethical desirability of adopting certain chemicals in the energy transition. Therefore it is necessary that the government has specified the intended use-cases for chemicals like green ammonia. This clarity can help address value conflicts related to competitiveness and environmental sustainability. Furthermore it is important that the government keeps fostering a strong collaboration between industry and government. This is especially important when adopting chemicals that are new and where the government possesses limited expertise on. As the industry could possess the necessary technical expertise, the government could set regulatory boundaries upon collaboration with industry, enhancing regulatory preparedness. Moreover, to ensure that imported ammonia is produced green, certification standards should be put in place. These interventions could address the identified value conflict between environmental sustainability and competitiveness, fostering the social acceptance of ammonia adoption.

Preface

The energy transition is not without its challenges, particularly when considering the value conflicts that arise in the adoption process of hazardous chemicals required for new energy systems. In undertaking this research, the main objective was to develop a methodological framework that integrates principles from systems engineering and value-driven design approaches to provide a structured approach to identify, classify, and address value conflicts that emerge when hazardous chemicals are adopted within the energy transition. The case study on ammonia serves as a practical evaluation of this framework, while at the same time offering insights for policymakers, industry stakeholders, and researchers on addressing these complex value dynamics. I hope that this work contributes meaningfully to the ongoing discourse on how to navigate the energy transition and developments in the field of value-sensitive design.

This research is performed in partial fulfillment of the requirements for the degree of Master of Science in Management of Technology at the faculty of Technology, Policy and Management of the TU Delft. The general criteria for graduation on this faculty are that he work contains an analytical component, it is multidisciplinary in nature and it focuses on a technical domain or application. This research fulfills all above requirements. By developing a methodological framework to analyze and navigate value conflicts concerning the adoption of hazardous chemicals in the energy transition, a systematic approach to make decisions and solve problems is provided. Hence, the work contains an analytical component and is performed focusing on a technical domain. Because the framework will have a value-driven component, not only technical aspects, but also social-, sustainability- and economic aspects are considered. As the framework will combine methods from the fields of energy systems design, technology adoption and acceptance and ethics of technology, the study is also multidisciplinary in nature.

Specifically for Management of Technology, one requirement is that the work shows an understanding of technology as a corporate resource or is done from a corporate perspective. Although this work focuses more on considering values in the technology adoption process in a broad way, it is of vital importance that corporate perspectives are also taken into. This is also reflected by the fact that expert interviews are conducted with companies who produce, transport or use potentially hazardous chemicals as their business model. Lastly, a typical Management of Technology project should use scientific methods and techniques to analyze a problem as put forward in the Management of Technology curriculum. This research uses methods from multiple courses to reach the research objectives. Especially the methods provided in the Research Methods course like scoping, research design and qualitative analysis provided useful. The project management and planning tools of the Digital Business Process Management course were also used extensively during this research process to reach all set milestones in time. Regarding the value-related part of this research, the course material of the Social- and Scientific Values course was also of vital importance.

As this work marks my last endeavour at the TU Delft, I would like to thank some people who supported me along the way. First of all, I would like to extend my gratitude to my thesis committee: Ming Yang, Sander Smit and Genserik Reniers. Your guidance, support, and expertise have been invaluable throughout this research journey. Next to my 'official' thesis committee, I also want to thank Anna Melnyk for the valuable discussions on considering values in socio-technical systems design. Additionally, I am grateful to the experts who participated in the interviews, sharing their insights and experiences which enriched the study. This research would not have been possible without the help of the people at the RIVM, of whom I learned a lot during my thesis internship. Mark, thanks a lot for all the nice sparring sessions and connecting me with the right people. You were a great mentor. Outside of academia, I want to thank my friends and family for being there for me when times were rough and always pushing me to achieve my goals. It would not have possible to get to this point without your support.

Sam Houdijk
Delft, June 2024

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Nomenclature

Abbreviation	Definition
ACM	Authority for Consumers and Markets
BRZO	Besluit Risico's Zware Ongevallen (Major Accident Hazards Decree)
EACP	Economic Affairs and Climate Policy
EU	European Union
IWM	Ministry of Infrastructure and Water Management
JRC	Joint Research Centre
J&S	Ministry of Justice and Security
LHC	Liquid Hydrogen Carrier
LIHC	Liquid Inorganic Hydrogen Carrier
LOHC	Liquid Organic Hydrogen Carrier
SMR	Steam Methane Reforming
OECD	Organization for Economic Cooperation and Development
RIVM	Rijksinstituut voor Volksgezondheid en Milieu (National Institute for Public Health and the Environment)
TRL	Technological Readiness Level
VSD	Value Sensitive Design
PD	Participatory Design
DfV	Design for Values
MCDA	Multi-criteria Decision Analysis
S-CBA	Social Costs-Benefit Analysis

1 Introduction

1.1. Problem Statement

After decades of ethical research, it has been established that technologies are strongly value-laden, as opposed to being value-neutral and merely practical objects (Winner, 1980). This means that the socio-technical systems where these technologies are adopted in are embedded with the values of those who design, develop, and implement them (Verbeek, 2006). Therefore, for technologies to be socially accepted by society, they need to be designed to align with the social and moral values of the affected stakeholders, like safety, sustainability and justice (van de Poel, 2013; Wüstenhagen et al., 2007). These values are not static, but change over time alongside technological advancements and shifts in society (van de Poel & Taebi, 2022).

If the values of the affected stakeholders are not sufficiently considered in the design of a technology, value conflicts can occur in the technology adoption process, which in turn can hinder the social acceptance of a technology (van de Poel & Taebi, 2022). By identifying potential value conflicts in the technology design process early on, actions to prevent social acceptance issues within a socio-technical system can be taken (Wildt, 2020; Wüstenhagen et al., 2007). This realization made that scholars started to develop methods to consider values and value conflicts in the adoption process of technologies within socio-technical systems, which marked the emergence of Value Sensitive Design (VSD) and Design for Value (DfV) approaches (van den Hoven et al., 2015; van de Poel, 2013; van Gelder, 2021). VSD and DfV approaches acknowledge the ethical aspects that are inherent to the often complex technologies that are needed in the worlds various transitions and have already been applied extensively across various fields including information systems design (Friedman & Hendry, 2019), urban design (Stone, 2021), and energy systems design (Correljé et al., 2015).

Recognizing the need to address the challenge of the energy transition, governments, industries, and local communities worldwide are navigating towards utilizing cleaner, more sustainable sources of energy for their energy systems design (Höfer et al., 2019). This can be considered a socio-technical design challenge, because the energy system encompasses both technological and social components that interact and influence each other (Polojärvi et al., 2023). To navigate this transition process, a wide array of energy sources needs to be evaluated for their feasibility and (ethical) desirability in the future energy system, such as nuclear and renewables (solar, wind, hydro, and geothermal), as well as more novel alternatives like hydrogen or bio-fuels. Within the pool of alternatives that are considered to play a role in the energy transition, potentially hazardous chemicals are present. This is for example the case with molecules like ammonia, methanol and toluene. These molecules are currently evaluated for their use as liquid carrier molecules for energy and hydrogen transport, as transporting hydrogen itself in a gaseous or liquid form is currently not always feasible (Arcadis, Berenschot & TNO, 2023).

The potential large-scale adoption of these hazardous molecules in the energy transition comes with certain ethical concerns (Bormans & Waarlo, 2024; RIVM, 2024; Stil, 2024), which rest on value conflicts between stakeholders (van de Poel, 2013). To be able to address the potential value conflicts between the stakeholders involved in the technology adoption process and foster the social acceptance of these molecules in the the energy transition, a holistic value-driven approach is needed. Methodological frameworks analyzing the values and value conflicts which play a role in the adoption process of sustainable technologies which are needed in the energy transition have been published for various physical technological artifacts like wind turbines, smart energy grids and nuclear reactors (Oosterlaken, 2015; van de Poel et al., 2020; Wildt, 2020). However, a value-driven framework to analyze value conflicts and potential social acceptance issues regarding the adoption of hazardous chemicals in the energy transition is lacking. Furthermore, while the value-driven frameworks in these studies have been demonstrated to provide a valuable way to analyze values and value conflicts in the design of sustainable energy technology, these studies often lack a way to classify and address value conflicts to be able to inform policy implications (Wildt, 2020).

1.2. Research Overview

1.2.1. Research Objective

Considering the found knowledge gaps, the first objective of this study is to develop a methodological framework to identify, analyze and address value conflicts in the adoption process of hazardous chemicals in the energy transition. Such an approach must delineate the socio-technical energy system wherein the chemical is adopted. Then, the framework should assist in identifying the values which play a role in the adoption process of that chemical within the energy system and be able to identify, classify and address potential value conflicts among stakeholders. The development of a value-driven methodological framework for this novel context will provide a relevant contribution to the field of value-driven design. The second objective of this study is to evaluate the developed framework by performing a case study on the values and value conflicts which play a role in the adoption process of ammonia in the Dutch energy transition. Reflection on the practical use of the developed methodological framework during the case study can then be used to derive points of improvement for future framework generations. Moreover, as this case study has not been described in the academic literature, the case study results will provide useful insights for policy-makers which need to foster the social acceptance of potentially hazardous chemicals to drive the energy transition.

1.2.2. Research Design

To reach the research objectives, two main research questions have been formulated. To develop the methodological framework, the following research question needs to be answered:

How can value-driven design methods be applied in a methodological framework to analyze values and address value conflicts in the adoption process of hazardous chemicals in the energy transition?

As outlined by McMeekin et al. (2020), methodological framework development generally consists of three steps (Figure 1.1). First, evidence to base the methodological framework on should be gathered. This can be done, amongst others, by comparing existing frameworks, guidance and methodology, analyzing literature and collaborating with experts. Second, the methodological framework should be developed based on systematic synthesis of the evidence identified in the first step. Third, the developed methodological framework should be evaluated and refined based on case studies.

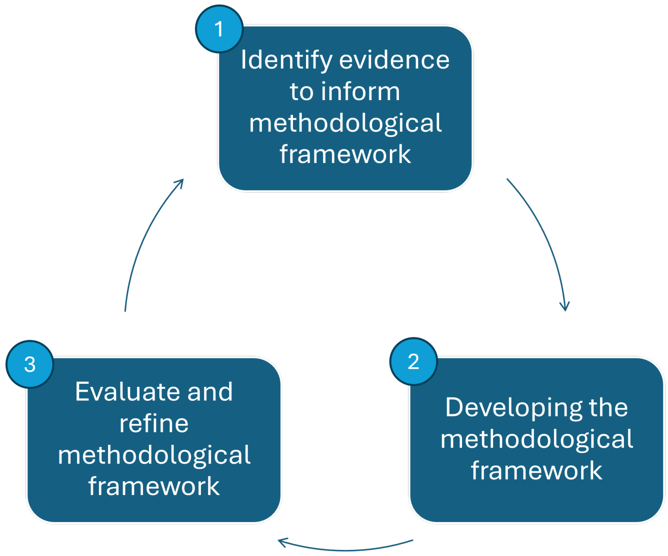

Figure 1.1: Steps in the development of a methodological framework (McMeekin et al., 2020).

To gather evidence to base the methodological framework development on, a systematic literature review on the connection between values and social acceptance of a technology and value-driven design methods will be performed (Chapter 2). As the socio-technical system wherein hazardous chemicals are adopted in is much broader than when considering physical technological artifacts like wind turbines or nuclear reactors, it will also be explored how the systems engineering approach can be used in the (value-driven) design of socio-technical systems. The literature review aims to answer the following sub-questions:

1. *What is the systems engineering approach and how can it be used in the design of socio-technical systems?*
2. *What are the strengths and weaknesses of the systems-engineering approach?*
3. *What is the importance of integrating values into the design of socio-technical systems for their social acceptability?*
4. *How can moral and social values be considered during the design of socio-technical systems?*
5. *How can value-conflicts be addressed during the design of socio-technical systems?*

The results from the literature review, combined with input from experts in the field of value-driven design methods and systems engineering, can then be used as evidence for the methodological framework development (Chapter 4, Section 4.1). To evaluate the methodological framework and use it to analyze the value conflicts that play a role in the adoption process of hazardous chemicals in the energy transition, a case-study concerning the adoption of ammonia in the Dutch energy transition will be performed (Chapter 4, Section 4.2). The results of this case study will give answer the second main research question:

What are the values and value conflicts which play a role in the adoption process of ammonia in the Dutch energy transition and how should these value conflicts be classified and addressed?

Discussion of the case study process and results can then be used to propose revisions to the developed methodological framework (Chapter 5). A visual representation of the research design of this study is shown in Figure 1.2.

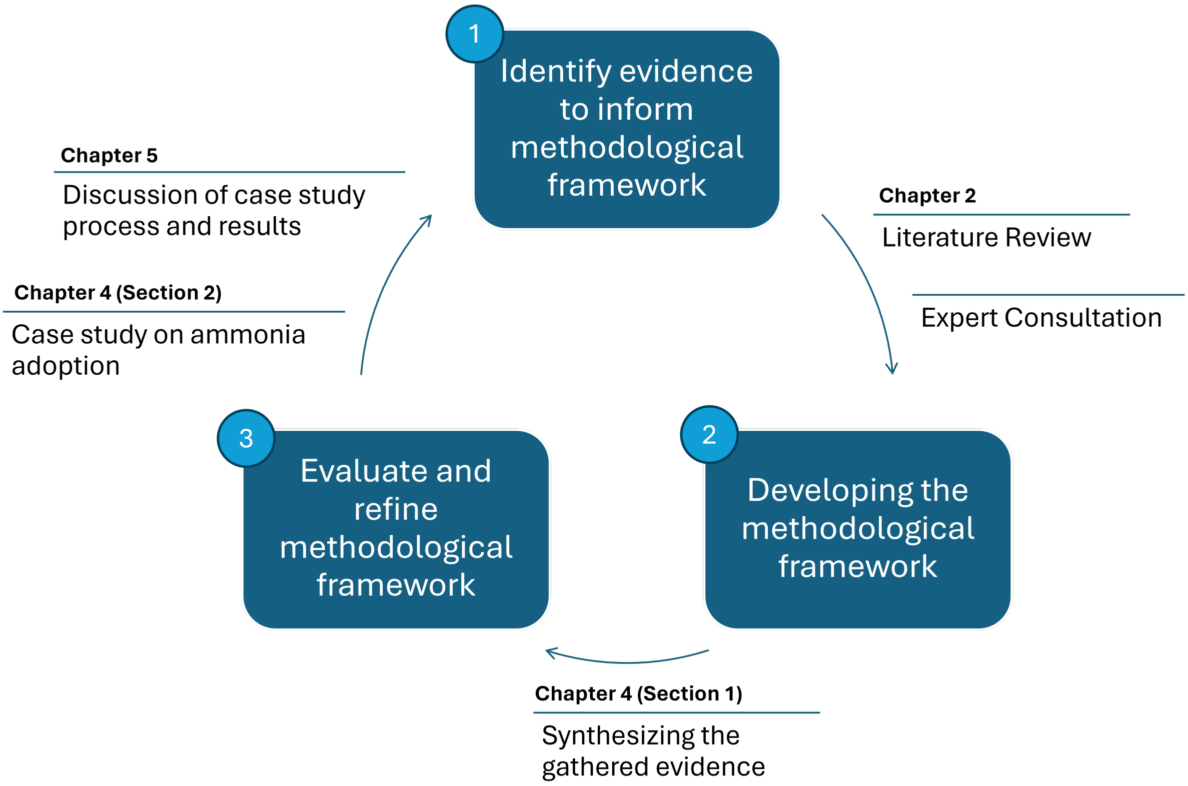

Figure 1.2: Research design of this Master thesis project (adapted from McMeekin et al. (2020).

2

Literature Review

This literature review was conducted to gather evidence to base the methodological framework development on. The used methodology to conduct the literature review is described in Appendix A.

This chapter delves into how we can analyze socio-techical systems, like the energy-system, and how we can consider values and value conflicts in socio-technical system design. We zoom into the Systems Engineering (SE) Approach and map the SE methods including their strengths and weaknesses. Then, the relationship between values and technology design, particularly focusing on the areas of technology adoption and social acceptance is analyzed. This all start by acknowledging the fact that technologies are inherently value-laden, embodying the values, norms, and requirements of their designers and the societies they emerge from. Finally, we analyze how values can be integrated in the design of socio-technical systems through the lens of value-driven methods like Value Sensitive Design (VSD) and Design for Values (DfV) approaches. This literature review consequently aims to answer the following questions:

Part 1. Systems Engineering Approach:

1. What is the systems engineering approach and how can it be used in the design of socio-technical systems?
   (a) What are the strengths and weaknesses of the systems-engineering approach?

Part 2. The role of values in the social acceptance of technological innovation:

1. What is the importance of integrating values into the design of socio-technical systems for their social acceptability?

Part 3. Incorporating values in the design of socio-technical systems:

1. How can moral values be considered during the design of socio-technical systems?
   (a) How can value-conflicts be addressed during the design of socio-technical systems?

2.1. Applying Systems Engineering to socio-technical systems

Historically, Systems Engineering has been important in the development and analysis of complex socio-technical systems such as aerospace, defense, and telecommunications infrastructures (Abbaspour, 2021; Burge, 2010; Elm, 2014). These systems often involve intertwined components that must operate reliably under challenging conditions. For example, in aerospace design, Systems Engineering has assisted in the integration of various technical components (e.g. propulsion, avionics, and structural integrity) with operational requirements (such as crew safety), making sure that these systems perform safely and effectively under all conditions (Burge, 2010). In this process, Systems Engineering (SE) considers both the business and the technical needs of all stakeholders, with the goal of providing a system that meets the user requirements (Sillitto et al., 2019). Furthermore, key to SE approaches is that they use a disciplined and structured approach that allows for efficient design and management of socio-technical systems over their life cycles (Kirkels et al., 2021).

Essential to SE approaches is the concept of systems thinking, which is an analytical approach that views complex systems as whole entities, rather than merely as collections of individual components (S. Davis & Sasaki, 2020). System engineering approaches typically begin with the identification of stakeholders, specifying the objective of the system, the system in- and outputs and the system constraints. Then, the stakeholders needs are analyzed and the definition of system requirements is established. These are then again divided in operational-, functional- and non-functional requirements (Datta, 2023). These requirements are then taken into account during the entire development process of the system. This ensures that all subsystems are integrated and function as a whole. Steps in this process can include project planning, testing, validation and verification. As the project progresses, systems engineers can use various tools and methodologies to manage process risks and optimize system- and subsystem performance. This set of methods can vary from project to project (Datta, 2023), but one of the main focus points of SE approaches is that communication among interdisciplinary teams is vital to address challenges during the design process. This collaborative environment helps to mitigate risks, while still fulfilling technical and functional requirements (Datta, 2023).

A few example of system-engineering approaches that are commonly used to analyze and manage socio-technical systems are Model-Based Systems Engineering (MBSE), Simulation-Based Design (SBD), systems-dynamics and stochastic methods. MBSE, SBD and systems-dynamics are utilized to simulate different system configurations. This can enable the prediction of outcomes under real-world scenarios (Banks et al., 2005; Estefan, 2008) and help to look into the long-term effects of policy changes and infrastructure investments (Sterman, 2000). Stochastic methods can be employed to handle uncertainties in system performance, using probabilistic models to address uncertainties in system behaviour (Billinton & Allan, 1984). Lastly, optimization techniques can be applied to discover the most efficient system configurations in terms of for example cost, performance, and resource conservation (Floudas & Pardalos, 2001).

2.1.1. Strengths and weaknesses of the Systems Engineering approach

Various reviews have been published which delve into the strengths and weaknesses of using the SE approach to analyze socio-technical systems. The main strength of using the SE Approach is that it is an holistic method; It provides a comprehensive framework that considers all aspects of a system's life-cycle, from development to operation. This ensures that the system's broader context and interactions are considered. Second, using SE fosters interdisciplinary integration. The method can facilitate the integration of different disciplines, bringing together various ways to address complex socio-technical challenges (Bauer & Herder, 2009). By providing freedom in the way the systems engineering approach is used by the practitioner, the practitioner can decide which disciplines need to be integrated method-wise. Third, using SE allows for risk management during the design and operationalization of socio-technical systems (M. Davis et al., 2014). The approach includes methods for identifying, assessing, and mitigating risks. This is important in managing socio-technical systems where social and technical elements are intertwined. Fourth, using SE allows for optimization of resources (Wu et al., 2015). By using optimization methods, SE encourages the efficient allocation and utilization of resources. If applied correctly, this enhances system performance and can increase for example sustainability. Lastly, SE approaches provide a user-centric design. By incorporating user requirements and feedback into the design process, systems are more likely to meet the needs of stakeholders and end-users (Sillitto et al., 2019).

In contrast, the main weaknesses of using the SE approach have also been identified. SE approaches can struggle with complexity. The complexity that SE helps to manage can also be a hindrance, as socio-technical systems are inherently complex and SE methods can sometimes be too rigid or linear to address system change and non-quantifiable factors (Ngowi, 2018). This can hinder decision-making. It is also argued that SE approaches lack social and human value integration (Longo et al., 2020; Strenge & Schack, 2020). While SE methods aim to integrate stakeholder requirements, they are not equipped to understand and incorporate social and moral values, or in other words, ethical considerations, in the design process. Socio-technical systems design frequently involves making normative decisions that have ethical implications, such as determining the placement of industrial facilities. This can lead to protests by local communities if not handled properly in the design process. This disadvantage is explained by the fact that SE approaches were originally developed to have a technology focus, emphasizing on solely providing technical solutions (Gorman et al., 2000). This can come at the expense of adequately addressing social and moral values during the design process.

2.2. The Importance of Values for Technology Acceptance

For technologies to be socially accepted by society, they need to be designed to align with the social and moral values of the affected stakeholders, like safety, sustainability and justice (van de Poel, 2013). These values are not static, they change over time alongside technological advancements and shifts in society (van de Poel & Taebi, 2022). For technologies to gain widespread acceptance, they must thus align with the prevailing values of the time (Wüstenhagen et al., 2007).

It is important to distinguish between the terms *ethical acceptability* and *social acceptance*. Both are essential for technology adoption (Poel, 2016). Ethical acceptability refers to the potential for a technology to be embraced based on its ethical characteristics and the moral values it embodies. It is a normative attitude towards technology. Social acceptance of a technology denotes the actual acceptance and use of the technology by society, which is descriptive and can be empirically observed (Poel, 2016). Wüstenhagen et al. (2007) distinguishes three different angels of technology acceptance, which are all necessary to foster social acceptance of a socio-technical system (Figure 2.1). At the socio-political level, acceptance is influenced by the policy environment and regulatory frameworks. This is acceptance in the broadest sense of the word. Market acceptance, or the process of market adoption of an innovation, focuses on the economic and financial dimensions of technological innovation. This includes consumer willingness to pay for the technology (either directly or with tax money) and investor confidence that the technology is economically feasible. Community acceptance considers the specific acceptance of technologies by communities which are directly impacted by that technology. This could for example be the case when making decisions on siting of renewable energy projects, like wind turbines (Künneke et al., 2015).

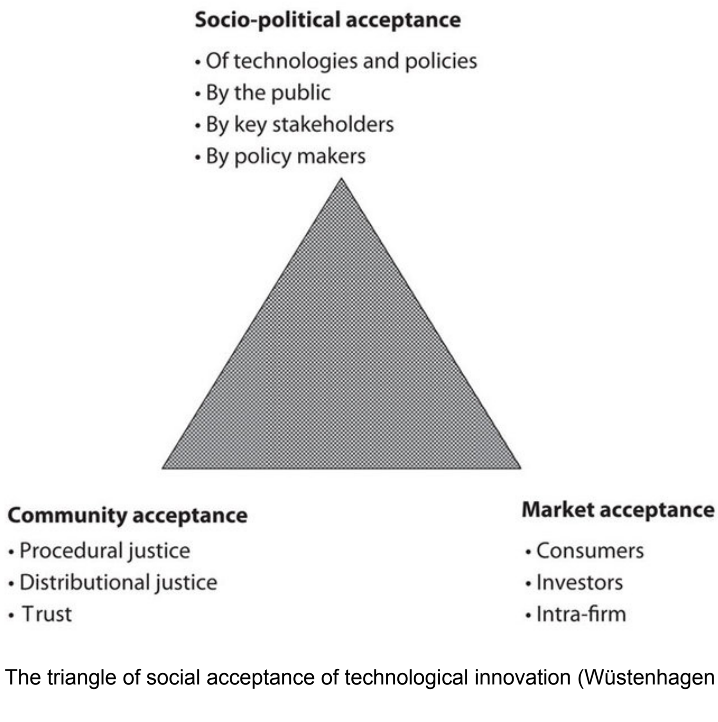

Figure 2.1: The triangle of social acceptance of technological innovation (Wüstenhagen et al., 2007).

2.3. Considering values in the design of socio-technical systems

After decades of ethical research, it is clear that technologies are strongly value-laden, as opposed to being value-neutral and merely practical objects (Winner, 1980). This means that socio-technical systems are embedded with the values of those who design, develop, and implement them (Verbeek, 2006). A famous example of a value-laden technology is the speedbumb used in road design. This technology invites normative behaviour; people who drive a car on a road with a speedbumb should reduce their speed when approaching the speedbumb, otherwise their car will get damaged. This is also why speedbumbs are sometimes ironically called ”dead-policeman” (van de Poel & Kroes, 2013).

As outlined in the previous section, one of the limitations of the traditional systems engineering approaches is that they are not well-suited to integrate social and moral values in the design process of socio-technical systems. This could hinder their social acceptance, and is also the reason why scholars started developing methods to properly integrate values in the design of socio-technical systems. It is important to clearly define what is meant with *values* in this context. In the context of integrating values into the design of socio-technical systems, values refer to certain things or states of affairs that are considered good or bad in a certain respect by individuals, groups, or society as a whole. These values influence decision-making during the design process and thus also influence how technologies are developed, implemented, and used (van de Poel, 2009). Examples of moral values can be fairness, justice and autonomy, which have a more ethical foundation (van den Hoven et al., 2015). Social values can be more related to human society, which include for example welfare, equity and sustainability (Wildt, 2020).

One way to account for values during the technological design process is to emphasize on the fact that stakeholder deliberation is important during decision-making processes. Participatory Design (PD) is such an approach, aiming to involve stakeholders in the design process to ensure the technology meets their needs and values (Spinuzzi, 2005a). This method does encourage feedback between direct stakeholders and the designer (in this case the decision-maker) during both the ideation phase and the development phase (Spinuzzi, 2005b). A limitation of PD approaches is that they often focus solely on direct stakeholders; those who are immediately affected by the technology, hereby missing the desires and needs of indirect stakeholders (Oosterlaken, 2015). Furthermore, PD approaches often consider only human values in the design process, not moral ones (Borning et al., 2004).

After PD approaches were developed, scholars tried to also include moral values in the design process of socio-technical systems. This marked the emergence of Value Sensitive Design (VSD) and Design for Value (DfV) approaches. These methods acknowledge the ethical aspects that are inherent to the often complex technologies that are needed in the worlds various transitions (van den Hoven et al., 2015). The methods have already been applied extensively across various fields including information systems (Friedman & Hendry, 2019), urban design (Stone, 2021), and energy systems design (Correljé et al., 2015).

2.3.1. Value Sensitive Design

VSD is an approach that aims to accounts for human and moral values throughout the design process. Oosterlaken (2015) draws a distinction between outcome-oriented and process-oriented approaches within the broader spectrum of VSD approaches. VSD can be used to incorporate both perspectives: it can be used to design technology that embodies certain values (outcome-oriented), while it can also be used for a design process that integrates values during the process (process-oriented). VSD approaches are characterized by the tripartite methodology which includes conceptual, empirical, and technical investigations (Figure 2.2) (Friedman et al., 2002; Umbrello, 2020).

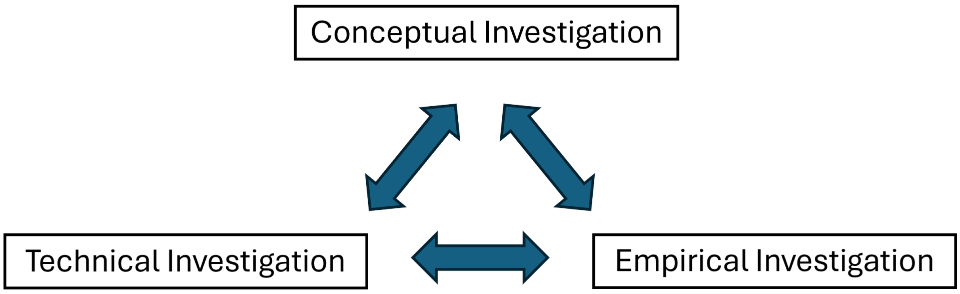

Figure 2.2: The tripartite VSD approach

Conceptual Investation
The conceptual investigation focuses on identifying stakeholders and the values important to them, exploring the potential impacts of technology on these values. It is important to note that the value identification in this phase remains conceptual, and is for example conducted by analyzing scientific (philosophical) literature. The conceptual identification of direct- and indirect stakeholder values is often seen as the foundational starting point of VSD approaches. With the output of the conceptual investigation, the empirical investigation phase can be initiated (Friedman & Hendry, 2019).

Emperical Investigation
Empirical investigations are employed to study how stakeholders experience or would experience the proposed technology design in relation to their values. In this phase, qualitative and quantitative methods like interviews, surveys and document analysis are used to translate the identified values into socio-cultural norms and policy requirements (Umbrello, 2020).

Technical Investigation
Technical investigations aim to integrate the findings of the conceptual and emperical analysis phases into the design of the technology. First, the technical limitations of the focal technology itself are evaluated for how they support/constrain identified values and policy requirements. This phase is iterative, with ongoing refinement of the technology design based on insights from each phase of investigation, ensuring that design decisions are sensitive to and supportive of the identified values (Correljé et al., 2015; Gerdes & Frandsen, 2023).

By making use of the tripartite methodology, VSD approaches can be used for five general outcomes, as outlined by Winkler and Spiekermann (2018):

1. Identification of direct and indirect stakeholders;
2. Identification and conceptualization of values;
3. Understanding of value harms and benefits (conflicts);
4. Development of mitigation strategies for value tensions
5. Presentation of (technical) measures to address values.

Existing VSD frameworks
Different VSD approaches and their outcomes are presented in various studies, of which we try to outline the most important ones.

Identifying and conceptualizing stakeholder values
Once direct and indirect stakeholders are identified, qualitative and quantitative empirical methods can be employed to investigate how stakeholders perceive and interact with technology. Such methods can range from surveys and interviews to observational studies. The difficulty with moral and human values is that they are latent topics (Wildt, 2020). They most often emerge from a certain context, instead of being articulated literally by interviewees or survey respondents. The way interviewees or survey respondents word certain values is dependent on many factors, including their field of expertise. A solution to this could be to use probabilities topic models, which makes value identification less dependent

on their scientific field and specific word use, as presented by de Wildt et al. (2018). This approach has been used to identify values across different scientific fields from a large amount of scientific literature. For relatively small datasets, like a set of expert interviews, performing thematic analysis by making use of inductive or deductive coding could also be a solution (Wæraas, 2022).

The method of describing *value scenarios* can be employed to illustrate the potential impacts of technology on stakeholders' values across various situations, aiding in the identification of potential conflicts and implications for both society and individuals (Friedman et al., 2002). Complementing this method are envisioning cards, a tool designed by the same authors to stimulate discussions about technology's impact on human values, prompting stakeholders to consider and weigh multiple perspectives of a technological impact (Friedman & Hendry, 2012).

Translating values into design requirements

While the methods discussed above can be used to consider values in the technology design process, they do not aid in translating values into concrete design requirements (van de Poel, 2013). Therefore, van de Poel (2013) proposed the value hierarchy method, which provides a systematic approach for translating abstract values into concrete design requirements (Figure 2.3). This hierarchical approach involves identifying core values and expressing them through associated norms, which in turn inform specific design requirements. The process can be applied either top-down or bottom-up. In his paper, van de Poel uses the method to translate the value *animal welfare* into corresponding norms and design requirements (EU policy guidelines).

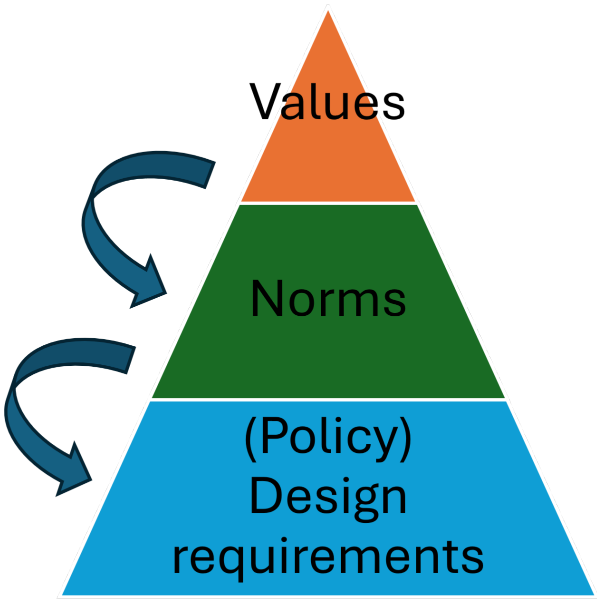

Figure 2.3: Value hierarchy as proposed by van de Poel (2013).

Since the development of Van de Poel's value hierarchy method, several researchers have expanded on the concept, applying it to various domains and refining the methodology to better integrate values into the design of socio-technical systems. In 2021, Umbrello and van de Poel (2021) specifically address the challenges posed by artificial intelligence systems. The focus of their VSD approach was laid on ensuring that AI developments embody certain ethical principles that reflect societal values and norms. Mouter et al. (2018) investigated how VSD could be applied to the Groningen gas controversy in the Netherlands, while Sapraz and Han (2022) explored the application of VSD in urban planning and development projects. Correljé et al. (2015), expanded the VSD approach by emphasizing the importance of rethinking institutional designs to prevent value conflicts in large-scale energy projects. They argued that, simultaneously with the technical investigation phase, VSD practitioners should also pay attention to design requirements to change institutional frameworks (e.g. laws, guidelines, codes of conduct).

Künneke et al. (2015) do not apply the value hierarchy framework of van de Poel, but develop a VSD-based framework that allows to make a systematic inventory of embedded social values of offshore energy systems. They relate these values to the effects on the social acceptability of these systems. The framework characterizes both objects and subjects of acceptability to identify areas where value conflicts might be present.

Adressing value conflicts

After value identification, conceptualization, and possibly converting the identified values to norms and (institutional and/or technical) design requirements, value conflicts between stakeholders can be analyzed and (possibly) addressed. This is vital to foster the social acceptance and efficient adoption of technologies (Kozlovski, 2022; Wüstenhagen et al., 2007).

Examples of value conflicts are widely-described in literature. In cybersecurity systems, security and privacy can clash when there is the need to secure data without authorized access (Niet et al., 2021; Umbrello, 2020; Umbrello & van de Poel, 2021). In energy systems design, the public is generally in favour of climate policy, but they do not like it if wind turbines are placed in their backyard (Oosterlaken, 2015). This is called NIMBY-ism (Not In My Backyard). Here, the values of sustainability and distributive justice (how much each individual has to contribute to the energy transition) are in conflict. In the case of the Groningen gas fields, for example the values of safety and security of energy supply are in conflict (Mouter et al., 2018). The Netherlands can continue to exploit the natural gas supply that is present in Groningen, but this comes at the costs of local inhabitants safety, who are the victims of increased earthquake risk.

Various works have been published on how to address value conflicts in the design of socio-technical systems. Miller et al. (2007) contributed the method of value dams and flows, which evaluates technical features or policies for potential value tensions, distinguishing between those that stakeholders oppose (value dams) and those they favor (value flows), to inform system redesign. The method was developed to assist in the design of a code-sharing platform, where it helped balance the privacy concerns of users (value dams) with the need for transparency on how contributions were used (value flows).

Where the method of value dams and flows stays relatively conceptual, merely analyzing value conflicts as opposed to resolving them, Van de Poel's work between 2013 and 2017 offers a more concrete way of addressing value conflicts (van den Hoven et al., 2015; van de Poel, 2013, 2017). Here, van de Poel introduces the concepts of *respecification* and *innovation* as strategies to handle conflicts that emerge within the value hierarchy. Respecification involves revising and possibly changing the conceptualization of values at one level of the hierarchy to resolve a conflict at another level. Innovation, on the other hand, suggests developing entirely new technological or institutional options that have not been considered previously.

An example from Van de Poel's work where value conflicts are adressed involves the development process of biofuels, where a conflict between sustainability goals (intergenerational justice) and current food security (intragenerational justice) was highlighted (Poel, 2017). Initially, innovation led to the proposal of third-generation biofuels made from bacteria and algae, which could potentially resolve the value conflict by eliminating competition for agricultural land. However, since these biofuels were still under research, respecification of the identified norms was necessary, shifting from a goal of no competition for agricultural resources to minimizing competition. This allowed the design to adapt to current technological limitations while still aiming to reduce conflicts between these competing values.

Sometimes, value conflicts cannot be resolved and decisions have to be made concerning the prioritization of multiple values. When it comes to decision-making about value conflicts within VSD, methods such as Social Cost-Benefit Analysis (S-CBA) and Multi-Criteria Decision Analysis (MCDA) are used to evaluate the impact of technology on stakeholders (Choy, 2018; Höfer et al., 2019). S-CBA quantifies the social and economic costs and benefits, while MCDA is a decision-making tool that evaluates complex situations involving conflicting and qualitative criteria, which are often values that cannot easily be quantified. In S-CBA, all criteria are converted into monetary values. This is a challenge, as criteria like sustainability and safety are often not converted easily in a weight or monetary value (Choy, 2018). In MCDA on the other hand, each criterion is typically assigned a weight based on its perceived importance relative to other criteria. However, the problem of parity arises when there is a disparity in how these weights are assigned, potentially leading to an overemphasis on certain values or goals at the expense of others (Kozlovski, 2022).This can result in decisions that are not truly reflective of all stakeholders' values or that disproportionately favor certain outcomes.

2.3.2. Design for Values

Next to VSD, Design for Values (DfV) also emerged as a value-driven design method to design technology or socio-technical systems in the academic literature. Although, VSD and DfV share much similarities, they have a different focus. Both methods can be performed bottom-up or bottom-down to identify stakeholder values and value conflicts (Mouter et al., 2018). However, where VSD has no specific initial value-focus in the design process, DfV methods approach design problems with a specifc value-focus in mind (Stone, 2021). It is thus an outcome-oriented approach. Examples are design for sustainability and safe-by-design approaches (van de Poel, 2017; van Gelder, 2021). It thus depends on the designers choice from which value-focus the design process is started.

3 Research Methodology

This chapter describes the methodology used in this study to achieve the research objectives as introduced in the introduction. As the objectives of this study are to develop a methodological framework and evaluate this methodological framework by analyzing what the values and value conflicts are which play a role in the adoption process of ammonia in the Dutch energy transition and how these value conflicts can be classified and addressed, methods from the fields of methodological framework development, systematic literature review and conducting case-studies based on qualitative data need to be combined.

This study consisted out of three parts: 1) A literature review on systems engineering approaches and value-driven design methods which can be used to analyze values and value conflicts which play a role in the adoption of hazardous chemicals within socio-technical systems. 2) The development of a scientifically sound methodological framework based on the evidence as put forward in the literature review and by consulting VSD and SE experts and 3) Evaluation of the methodological framework by performing a case study on analyzing the values and value conflicts which play a role in the adoption of a hazardous chemical in the energy transition. The process of using the methodological framework and output of the case-study were then evaluated, which led to future recommendations on the (use of) the framework.

3.1. Developing the methodological framework

To develop the methodological framework, the gathered evidence from the literature review (see Appendix A for method) was used as well as discussions with experts from the field of systems engineering and ethics of technology. According to McMeekin et al. (2020), it is important that a researcher explains why certain choices in a framework development process were made and that scientific evidence to back up those choices is given.

3.2. Methodological framework evaluation by performing a case study

To evaluate the developed methodological framework, a case study was conducted to evaluate the working of the framework and evaluate if changes to the framework protocol need to be made. This case-study also allowed to answer the second research question concerning the values and value conflicts which play a role in the adoption process of ammonia in the Dutch energy transition.

Case Study Scope

For the case study, a representative discussion about the adoption of a potentially hazardous chemical in the energy transition was required. Therefore, it was decided to zoom into the geographical context of the Netherlands. Here, currently a debate is held about using different chemicals, amongst others ammonia, as a sustainable alternative for hydrogen and energy transport within the Dutch energy transition. For the case study in this research, specifically ammonia was chosen as chemical, because the debate on its potential adoption recently received a lot of attention from newspapers, knowledge institutes and local and national politics (Arcadis & Berenschot, 2021; Bormans & Waarlo, 2024; Ministry of Economic Affairs and Climate, 2023; Stil, 2024). Ammonia has already found its place in various industrial applications, like fertilizer production or the chemical industry, with established knowledge regarding its properties and associated safety- and environmental risks (Arcadis, Berenschot & TNO, 2023). However, while its use in industry is known and manageable within controlled environments, the prospect of scaling up their application as energy or hydrogen carrier for national or global hydrogen transport presents certain ethical dilemmas. The plans for construction of large ammonia terminals in the port of Rotterdam and the large-scale transport of ammonia over rail in Amsterdam causes concerns among local communities due to the hazardous properties of the chemical. In the adoption process, trade-offs need to be made by the government between advancing the energy transition, spatial planning and ensuring public safety and environmental sustainability. This was also outlined by recent reports of the Dutch National Center for Public Health and the Environment and consultancy firms Arcadis, TNO and Berenschot (Arcadis & Berenschot, 2021; Arcadis, Berenschot & TNO, 2023; RIVM, 2024). The authors of these studies all argue that the adoption of hazardous liquid hydrogen carrier molecules like ammonia in the energy transition does not only require the consideration of safety concerns, environmental impact or public health implications, but also economical- and technical factors, and demand an holistic consideration of all these aspects for policy development.

Defining the socio-technical system of ammonia adoption
Systems Thinking was used to define the socio-technical system in which the chemical of interest, ammonia, is adopted. This process was informed by attending multiple expert meetings and conducting unstructured interviews with employees of the RIVM (Appendix B). For the stakeholder analysis, a power-interest grid was constructed (De Colle, 2005).

Expert Interviews
Semi-structured interviews were chosen as the primary method to collect empirical data on the values and value conflicts which play a role in the adoption process of ammonia in the energy transition. This method allows for flexibility during the interview process, enabling the interviewer to explore topics of interest as they emerge from the interviewees answer. The method furthermore allows for manipulating the interview structure/questions so that a connection with the participant can be established and the maximum amount of relevant data can be collected (Adams, 2015). Approval for conducting the interviews was granted by the Human Research Ethics Committee of the TU Delft on March 19th, 2024 (Appendix C).

The selection of participants for the semi-structured interviews was conducted using the snowballing method. This approach was essential to ensure a comprehensive representation across the entire stakeholder landscape. A stakeholder analysis conducted earlier identified key stakeholders (Figure H.1), which could mainly be categorized into public (government and local communities) and private stakeholders (industry). This preliminary stakeholder analysis was also performed by attending multiple expert meetings and conducting unstructured interviews (Appendix B). The focus during participant selection was to select stakeholders who could provide diverse perspectives on the adoption of ammonia in terms of market dynamics, socio-technical aspects, and local community impact.

The interview participant recruitment process began with contacting a few key informants in the network of the RIVM, who then provided referrals to other potential participants. Interviews were conducted until a point of data saturation was reached. This point occurred when no new information or themes were observed in the data. The participants ranged from researchers from public research institutes and policy advisors to consultants and managers of ports, rail-companies and market players.

Table 3.1: Interview participants and their role in a public or private organization

Interviewee Number	Public/Private	Role
1	Public	Researcher Industrial and Environmental Safety
2	Public	Researcher Industrial and Environmental Safety
3	Private	Safety Consultant
4	Public	Policy Advisor Ammonia (I&W)
5	Public	Policy Advisor Crisis-Management (J&V)
6	Public	Policy Advisor Risk-Policy Hydrogen Transport (EZK)
7	Private	Energy Transition Consultant
8	Public	Policy advisor transport of dangerous substances (ProRail)
9	Private	Senior Analyst Capacity Development (E-fuel producer)
10	Private/Public	Program Manager Policy and Planning (Port)
11	Private	Consultant Ammonia Terminals

As the goal of the interviews was to distill values and value conflicts out of the qualitative data, the interview protocol was based on other studies which had the same goal (Boijmans, 2019; Correljé et al., 2015; de Geest, 2016; Wildt, 2020). The interview protocol was also discussed with an expert in systems engineering and ethics and philosophy of technology, to ensure that the questions were suitable to answer the research questions. After a general introduction, it was asked what the context of the participant in the adoption of ammonia in the energy transition was. Then, questions were asked about the ethical dilemmas in the adoption of ammonia in the energy transition and how to overcome these from a technological or institutional perspective. Depending on the interviewee, additional questions were asked. The used interview protocol is presented in Appendix D. The inverviews generally took 30-45 minutes. To eliminate the effect of asking too many leading questions, the interview ended with the question:

"Do you think there is anything we have not discussed yet regarding the ethical dilemmas, values or value conflicts which play a role in the adoption of ammonia in the energy transition?

The interviews were conducted using MS-Teams, which allowed to automatically transcribe the interviews while the interview was ongoing. The raw interview transcripts were then polished using the Word text editor by comparing the transcript to the video recording of the interview.

Thematic Analysis
To analyse the values and value conflicts which play a role in the adoption process of ammonia in the energy transition, a qualitative content analysis was performed on the interview transcripts. To do this, a systematic coding process was followed. The primary goal of this process was to extract and analyze value-laden statements that highlighted societal, technical or ethical considerations in the debate over the adoption of ammonia in the energy transition.

The thematic analysis was initiated with a deductive coding approach, using a predefined list of values identified from the literature (Dignum et al., 2015; Milchram, Hillerbrand, et al., 2018; Wildt, 2020). These values, which were identified to be relevant in discussions about the exploitation of shale-gas and the design of smart-grid energy systems, served as a foundation for the initial coding categories. As put forward in Wildt (2020), values are often latent and may not be explicitly stated in the text. This is why semantic fields related to these values were composed. For the values safety and health, justice, efficiency, competitiveness and reliability, the semantic fields composed by Wildt (2020) were taken. For the other values, the semantic field was composed by the author of this research. The semantic fields were cross-checked by experts of the RIVM to ensure their validity. The composition of the semantic fields helped in recognizing various statements related to the deductive values without mentioning those values literally.

To complement the deductive codes, inductive coding was used to allow new themes to emerge from the data, following the *sensitizing concepts* methodology (Bowen, 2006). This approach ensured that the analysis remained open to discovering new values and value conflicts that were not initially anticipated based on the literature. The actual coding process was guided by a set of principles as outlined in Appendix E. This ensured consistency and reliability in how data was interpreted and categorized.

Analysis and Interpretation

Following the coding process, the analysis phase involved examining the compiled values and value-laden statements to identify value conflicts in the adoption of ammonia in the energy transition. The coded values, norms and design-requirements were analyzed by constructing value hierarchies as proposed by van de Poel (2013). Identified value conflicts and the potentially resulting social acceptance issues were classified and analyzed according to the approach of Wildt (2020). Lastly, possible ways to deal with the value conflicts by imposing innovative technological or institutional design requirements, or enhancing or creating stakeholder interactions, were given by answering the questions as proposed in Correljé et al. (2015).

4 Results

The goal of this chapter was to develop a methodological framework which can be used to identify, analyze, and possibly address value conflicts in the adoption of hazardous chemicals in the energy transition. The framework development explored how principles of the systems engineering approach and value-driven design methods can be combined. To evaluate the developed methodological framework and answer the first research question, a case-study on analyzing and addressing the values and value conflicts in the adoption of ammonia in the Dutch energy transition was performed. The results of this case study will be used to answer the second research question regarding the values and value conflicts that play a role in the adoption process of ammonia in the Dutch energy transition.

4.1. Methodological Framework Development

Synthesizing the information from the literature review, a methodological framework to identify, analyze, and possibly address value conflicts in the adoption of hazardous chemicals in the energy transition was developed (Figure 4.1). The framework steps follow the tripartite methodology, which is the foundation for value-driven design methods like VSD and DfV (Umbrello, 2020). Using this framework, the five potential outcomes of VSD approaches as described by Winkler and Spiekermann (2018) can be achieved.

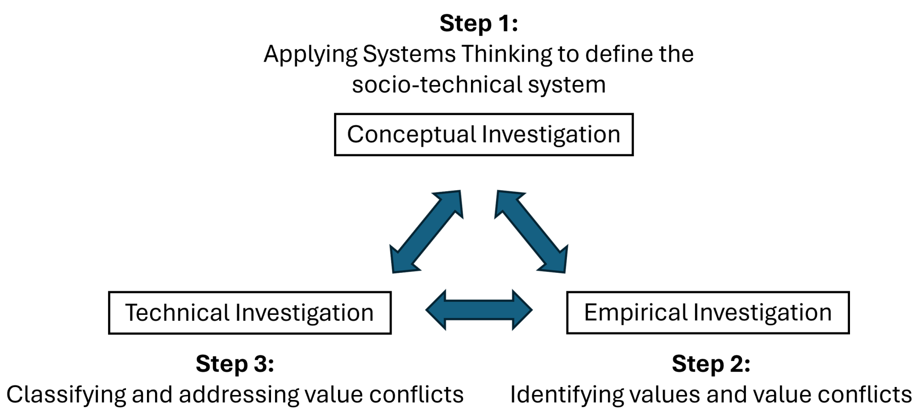

Figure 4.1: Developed methodological framework to identify, analyze, and possibly address value conflicts in the adoption of hazardous chemicals in the energy transition.

Step 1: Defining the socio-technical system

When analyzing the studies that reflect on value conflicts of technological innovation and adoption in the literature review, it became apparent that the employed methodological frameworks in those works often focus on specific technological artifacts like wind-turbines, nuclear reactors or smart electricity grids. For example, the placement of wind-turbines mostly affects local stakeholders in terms of the aesthetics of their living environment and possible wildlife disruption. Similarly, nuclear reactors affect local communities because they could be put in peoples sight, and in this case, also public safety concerns play a role. However, the adoption of a chemical in the energy transition represents a broader set of challenges and considerations. Unlike a physical piece of technology that is installed or employed somewhere, a chemical molecule can be imported from abroad, transported within a country, and have multiple use-cases depending on the type of chemical. This means that there is a broader scope of stakeholders involved, with wider institutional implications than described in the present literature regarding value conflicts in the adoption of energy project in the energy transition. Thus, studying the potential value conflicts in the adoption process of hazardous chemicals necessitates a different methodological framework which can be used. Because the adoption of a potentially hazardous chemical is often not a small-scale, local, energy project, it is of vital importance that the socio-technical system in which the chemical will be adopted is defined clearly. This ensures identification of all direct- and indirect stakeholders involved with the adoption of the chemical and prevents that important values or value conflicts in the adoption process will be missed. As part of the conceptual investigation, which is one of the three components of VSD-methods, the values of the identified stakeholders will be conceptualized. Apart from stakeholder identification, the goal of defining the socio-technical system should be to specify the the boundaries, in- and outputs, constraints of the chemical in the socio-technical system. Furthermore, the objective of the use and transport of the chemical should be specified. This information can then be used as context for studying the ethical dilemmas in the adoption process. Reflecting on the evidence in the literature review, the Systems Thinking principle could be utilized for this purpose since it is a holistic approach that focuses on the way that different system's parts interrelate and how smaller systems work within the context of larger systems (Arnold & Wade, 2015). By re-applying the Systems Thinking approach when new chemicals are considered, the methodological framework should be suitable to be adapted to analyze every chemical in every geographical and socio-technical setting.

Within the methodological framework, it is proposed that the following questions, which are composed based on the highlighted studies in the literature review, should be answered by the user to define the socio-technical system in which the chemical is used:

1. **Defining the objective of use and transport of the chemical**
    - Analyze the role and purpose of the chemical within the context of the energy transition.
2. **Defining system boundaries**
    - Define the physical boundaries of the system under consideration, specifying which elements are included and excluded.
3. **Defining system inputs and outputs:**
    - **Inputs:** All resources required for the system to function.
    - **Outputs:** All products, waste materials, and emissions resulting from the system operation.
4. **Defining system constraints:**
    - Outline the limitations and restrictions that influence the system's performance.
5. **Defining stakeholders and stakeholder interactions:**
    - Identify all stakeholders involved (direct stakeholders) or affected (indirect stakeholders) by the system.
    - Define the power- and interest of all identified stakeholders in the socio-technical system, related to the adoption of the chemical.
    - Describe the interactions and dynamics between stakeholders

The other components of the systems engineering approach were not found to be useful for application in a methodological framework to analyze value conflicts in the adoption process of a chemical in the energy transition, because they have too much technology and engineering focus.

Step 2: Identifying Values and Value Conflicts

After Systems Thinking has been applied to define and delineate the socio-technical system in which the chemical of interest is adopted, the ethical dilemmas and value conflicts which arise in the adoption process can be analyzed as part of the empirical investigation. To be able to do this, first information about the social- or moral values which play a role in the adoption process of a specific chemical should be collected. From the stakeholder analysis in the first step of the framework, stakeholders can be identified which need to be consulted to gather data. Data collection can be performed by for example conducting a survey, organizing focus-groups or using expert interviews. The qualitative data that comes out of the data collection needs to be coded to identify social- and moral value-laden statements (Wæraas, 2022). By making use of semantic fields, value-laden statements in the data can be recognized and coded, identifying patterns and allowing to uncover ethical dilemmas (Wildt, 2020). Depending on the type of data collection, and the expertise of the consulted stakeholders on the field of ethics of technology, the stakeholders can be asked about ethical dilemmas and values which play a role in the adoption process. If the stakeholder is not knowledgeable enough about ethics of technology and is not acquainted with considering values in a technological design and adoption process, the user of the methodological framework can also ask about institutional or technical design requirements that need to be in place in the socio-technical system to foster successful adoption of the chemical. These can then also be translated to underlying values bottom-up, as is proposed by van de Poel (2013) (Figure 4.2). When the consulted stakeholder is knowledgeable enough to reflect directly on the concerned values and ethical dilemmas in the adoption process, values can be derived top-bottom. These values can then be translated into norms and technical- and institutional design requirements if desired.

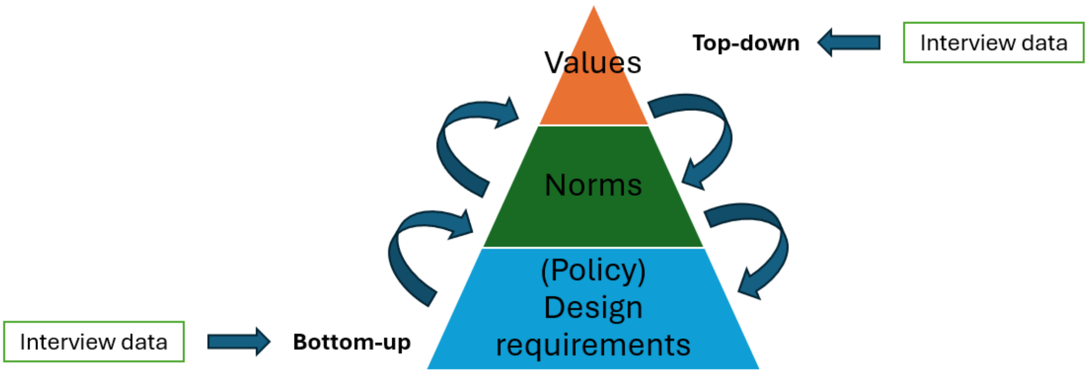

Figure 4.2: Value hierarchy as proposed by van de Poel (2013), constructed bottom-up and top-down based on how knowledgeable the consulted stakeholders are. In this case, interviews are used to collect data from stakeholders

After value identification and constructing value hierarchies, it can be analyzed which value conflicts play a role in the adoption of a chemical in the energy transition. These value conflicts can be derived from comparing the norms related to the identified values. If for example the values Safety and Competitiveness are identified, with respectively the corresponding norms "the transport of chemical X should be as safe as possible" and "the transport of chemical X should be as cheap as possible", it can be concluded that these two values can be conflicting because safety measures always cost something. The comparison of norms from the constructed value hierarchies can be complemented by analyzing the reflection on ethical dilemmas which interviewees observe or expect in the adoption process of a chemical. Again, this can be done top-down (by asking the stakeholder about conflicting values directly) or bottom-up (by asking how different technical or institutional design requirements are, or can become, conflicting), depending on the knowledge level of the consulted stakeholders.

Step 3: Classifying and addressing value conflicts

The identified value-conflicts that potentially play a role in the adoption of the chemical should be classified in order to prioritize which value-conflicts to address first. This classification can then be used by engineers or policy-makers to derive technical design or policy actions. This part of the framework forms the technical investigation part of this work. The possible implications of the value conflicts will be analyzed by specifying the possible social acceptance issues which can arise if the value conflicts are not dealt with (Figure 4.3). This will be done by reflecting on the three types of social acceptance issues as outlined by Wüstenhagen et al. (2007) and is also proposed in the methodological framework of Wildt (2020).

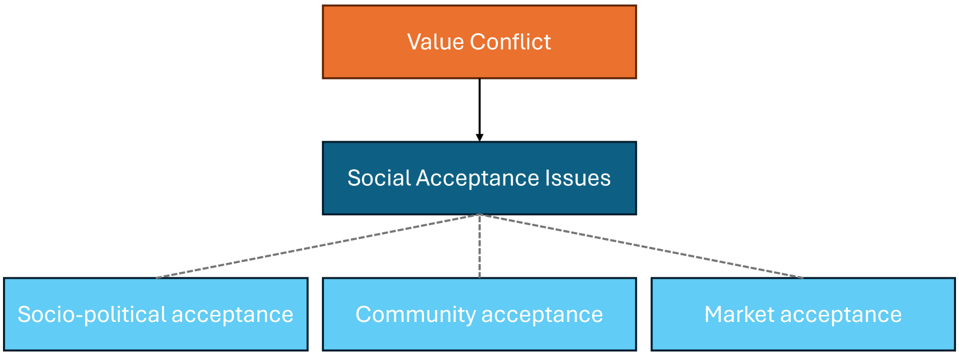

Figure 4.3: Analyzing social acceptance issues which could result from value conflicts, based on Wildt (2020) and Wüstenhagen et al. (2007).

Wildt (2020) propose that to be able to further classify the value conflicts, first the resources to resolve the value conflict must be analyzed. In this study, the author does not reflect on the method which was used to arrive at the resources that are needed to resolve the value conflict. According to Van de Poel, in van den Hoven et al. (2015), the six approaches to deal with value conflicts are Cost-Benefit Analysis, Direct Trade-Offs, Maximin, Satisficing, Judgement: Conceptualization and (Re)specification, and Innovation. The first three methods suppose a specific form of value commensurability, which means that they are compared by using the same common standard or measurement. This makes making trade-offs convenient, but has the disadvantage that it can be challenging to express different values in the same standard or measurement to be able to compare them. The last three methods do not aim for one best option, but allow room for multiple options to be chosen. In line the work of Correljé et al. (2015), we focus in this work on the innovation approach to deal with value conflicts, both from a technical- and an institutional viewpoint. Developing institutional design requirements requires interaction between stakeholders, which is why this is also taken along in this analysis. We therefore here propose that the resources needed to resolve the value conflicts can be identified by answering the three questions as mentioned in Correljé et al. (2015):

- Are there any values and/or norms missing in the current technological design? How can these be specified into design requirements?
- Are there any values and/or norms missing in the current institutional context? How can these be specified into design requirements?
- Do the processes in which the different groups of stakeholders interact allow for the specification of all stakeholders' values?

Lastly, the degree of resolvability of the value conflict should be analyzed by literature analysis. If no knowledge on the degree of resolvability of a value conflict is found, the user of the framework should try to obtain a scientifically sound estimate of the resolvability. The identified value conflicts can then be classified by the degree of severity of the resulting social acceptance issues, the degree of resolvability of the value conflict and the required resources for the resolution of the value conflicts as is also done by Wildt (2020) (Figure 4.4). This allows for reflecting on policy-implications which could be considered to increase and foster social acceptance of the adoption of the chemical in the energy transition.

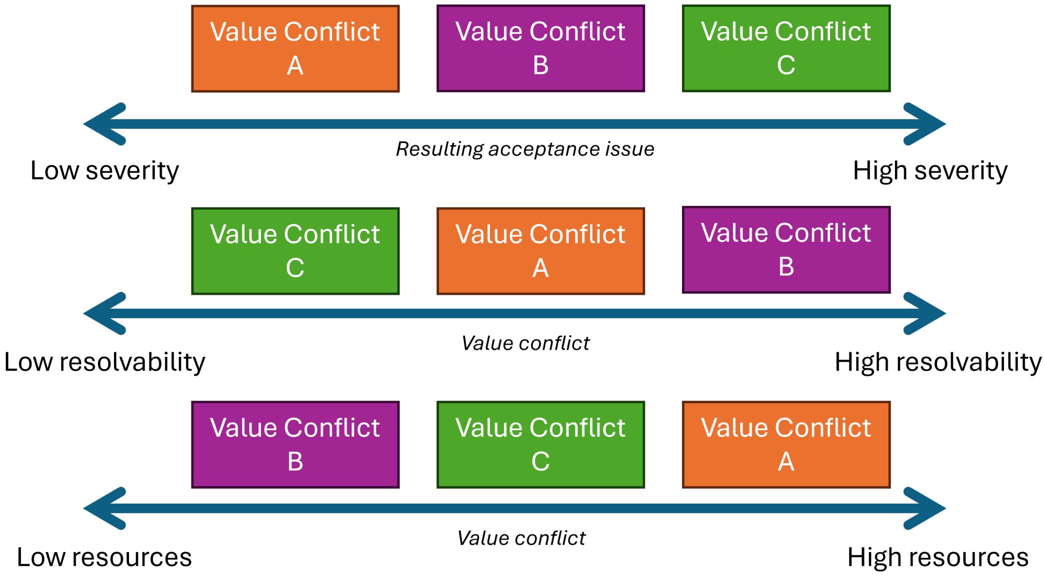

Figure 4.4: Analyzing social acceptance issues which could be caused from value conflicts, based on Wildt (2020) and Wüstenhagen et al. (2007).

4.1.1. Knowledge exchange between different framework steps

As described in Umbrello (2020), the three investigation phases of the tripartite VSD approach (conceptual, empirical and technical) are iterative and must be treated as a continuous feedback cycle. We here propose to start with the conceptual investigation, followed by the empirical investigation and the technical investigation. This order is however not strict in practice, as there is knowledge exchange and feedback between these different steps during the process (indicated by the double-sided arrows in Figure 4.1). For example, during the empirical investigation phase, consulted stakeholders are asked about their role in the adoption process and the other stakeholders they consider important in the adoption process. This can identify new stakeholders which can be taken along in the conceptual investigation phase. The same knowledge exchange occurs between the empirical and technical investigation phases. In the empirical investigation phase, values and value conflicts in the adoption process are identified. The technical investigation phase then aims to address and classify the value conflicts, which can also lead to the discovery of new value conflicts, which can be fed back into the empirical investigation process. The process of framework use can thus be seen as an iterative process.

4.2. Framework evaluation: Ammonia adoption case-study

To evaluate the developed methodological framework, a case-study on analyzing the values and value conflicts in the adoption of ammonia in the Dutch energy transition was performed. The outcomes of the case study will be used to refine the framework, as well as derive insights for policy implications.

4.2.1. Step 1: Defining the socio-technical system

As first step in the methodological framework, the socio-technical system is defined in which the chemical of interest, here ammonia, is adopted. This will be done by using the Systems Thinking's approach to delineate the socio-technical system as described in the methodological framework development section.

The objective of using ammonia in the Dutch energy transition

Before ammonia can be used in the energy transition, it first needs to be produced, as it is not present in large amounts in the natural environment. The production of ammonia relies on the Haber-Bosch process, which combines nitrogen from the air with hydrogen derived from natural methane gas in the presence of a catalyst at high temperatures and pressures (Niermann et al., 2021). This production method produces the so called "grey" hydrogen, referring to its reliance on fossil fuels (Figure 4.5). As almost all ammonia is currently produced using this method, ammonia production accounts for approximately 1% of the worlds carbon emissions and 2% of the world's energy consumption (Ye & Tsang, 2023).

A less polluting production process can be achieved if the created CO2 by the process of steam methane reforming is captured and stored (CCS). The produced hydrogen is then called "blue hydrogen". However, to align with the net-zero goals as put forward in the climate agreement, the produced ammonia needs to be "green". This means that the production method must use renewable energy sources to produce hydrogen via electrolysis, which is then combined in the Haber-Bosch process with nitrogen gas to form ammonia (Figure 4.6). Looking at the amounts of carbon emission and energy consumption of the current ammonia production, substituting grey ammonia with green ammonia will contribute substantially towards a more sustainable future.

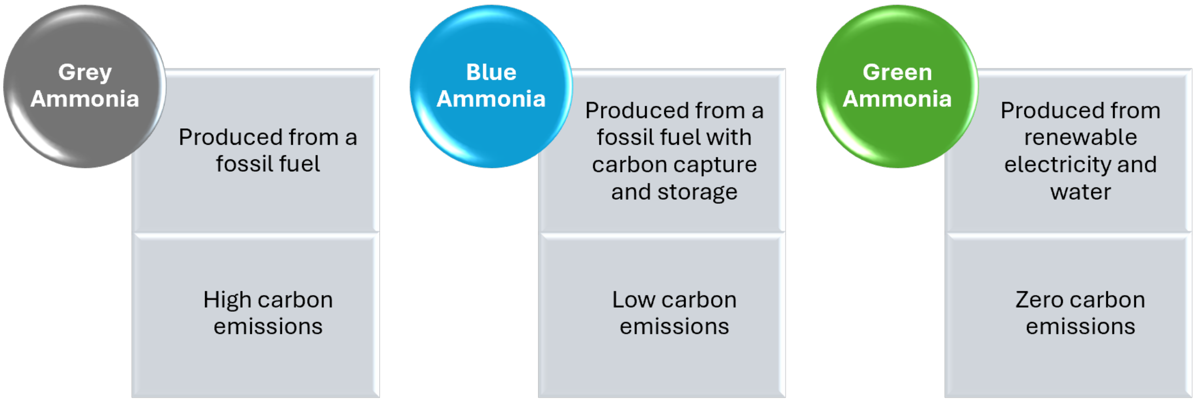

Figure 4.5: Different production methods of ammonia and corresponding sustainability "colour-codes".

Apart from substituting grey ammonia with green ammonia, the adoption of ammonia in the energy transition can serve other objectives which can contribute to sustainability targets (Figure 4.6). The chemical can be used directly as a fuel in combustion engines or in fuel cells to generate electricity (Clematis et al., 2023). It could then for example be used as a fuel in the shipping industry or in a coal-fired power plant (Andriani & Bicer, 2023; Yara, 2023). This second option is currently under investigation in Germany and Japan, which both still make extensive use of coal-fired power plants (Brown, 2024; Schmitz, 2022). In the Netherlands, only using ammonia as a shipping fuel is currently considered to reach the Dutch climate goals (Buitendijk, 2022).

In the energy transition plans of most countries, hydrogen has also emerged as a promising green energy carrier, which can be used to help decarbonize various sectors, including the mobility and chemical industry. Particularly in sectors where electrification is challenging, hydrogen is foreseen to be the next-best candidate to achieve set sustainability goals. In the Netherlands, the government has set ambitious goals for hydrogen import and production, which is needed to fulfill the ambition of using only sustainable energy sources by 2050 (Ministry of Economic Affairs and Climate, 2023). However, the widespread adoption of hydrogen as energy carrier faces challenges, particularly in terms of transportation. The light molecule does not occur in nature and is therefore typically produced at centralized facilities using electrolysis or steam methane reforming and must be transported to end-users, often over long distances (Arcadis & Berenschot, 2021). Recently it was concluded that the existing natural gas pipeline infrastructure in the Netherlands can be used for gaseous hydrogen transport in the future (the so called "Hydrogen Backbone") (PWC, 2021). But, this transition will take time and pipelines are anyway not feasible for long-distance transport of hydrogen. Hydrogen itself can be used as a liquid carrier by cooling it to a temperature of -253°C. However, large-scale transport of this so called cryogenic hydrogen is not feasible using the currently available technology and is therefore not ideal for transport of hydrogen (Clematis et al., 2023). To be able to transport hydrogen over short distances (<1000 km) awaiting the transformation of the natural gas grid and also be able to transport hydrogen over long distances from import from the Dutch ports into the European mainland, ammonia is proposed as a promising alternative for hydrogen transport (Arcadis & Berenschot, 2021). This can be achieved by coupling hydrogen to nitrogen gas before transport via the Haber-Bosch process. At the destination location, the ammonia can be cracked to release the hydrogen. The harmless nitrogen gas is then released into the atmosphere (Figure 4.6).

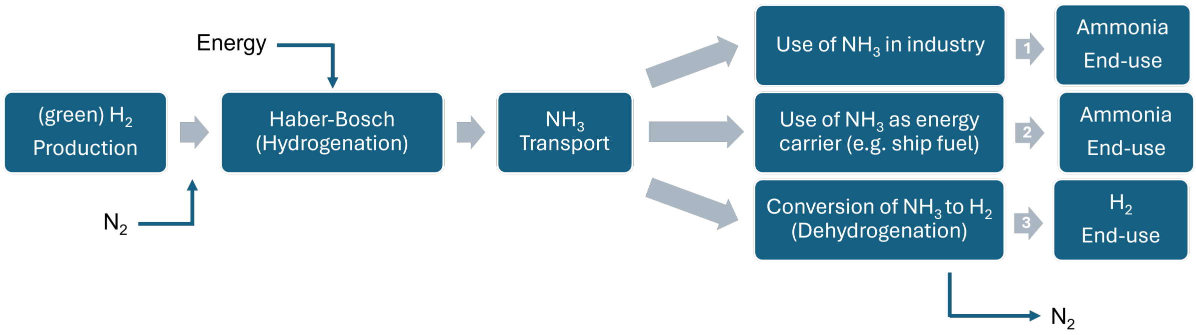

Figure 4.6: Different use-cases for ammonia in the energy transition

One of the primary reasons ammonia is considered a strong candidate for liquid hydrogen transport and storage is its hydrogen density. Ammonia contains 17.6% hydrogen by weight, which is relatively high compared to other potential hydrogen carriers (Andriani & Bicer, 2023). This hydrogen density means that ammonia can contain a relatively high amount of hydrogen in a relatively small volume. Additionally, ammonia's physical properties make it easier to handle than liquid hydrogen. Ammonia can be liquefied at -33°C under atmospheric pressure or at room temperature under moderate pressure (about 10 bar). Another positive factor is that there already is available transport technology (ships, trucks, rail wagons, pipelines) and a well-established global infrastructure for the production, storage, and transport of ammonia (Arcadis & Berenschot, 2021).

System Boundaries and In- and outputs

The socio-technical system under consideration for the adoption of ammonia as a hydrogen carrier includes several physical boundaries. First of all, the geographical context of the socio-technical system should be considered. For this case-study, it was chosen to focus on the adoption of ammonia in the Dutch energy transition. As it is expected that not all ammonia that is needed in the Dutch energy transition will be produced in the Netherlands, also import from abroad is expected to take place (Arcadis & Berenschot, 2021; Arcadis, Berenschot & TNO, 2023). It is assumed that this ammonia will arrive via ship, as there is currently no pipeline infrastructure available for large-distance transport of ammonia. After port import, the ammonia can either be transported into the country via existing transport infrastructure via modalities like rail, road or water. If ammonia pipeline infrastructure is available, like is currently discussed in the plans for the Delta-Rijn corridor, then the ammonia could also be transported via pipeline (Arcadis, Berenschot & TNO, 2023). After storing the ammonia at the destination location, either inside the Netherlands or outside the Netherlands, e.g. in the German Ruhr-area. It can then be either used directly for use in the chemical industry or fertilizer production industry, or it could be cracked to obtain hydrogen gas. The ammonia could also be cracked directly after its arrival in the port, and it then depends on the availability of a pipeline for hydrogen gas (e.g. the Hydrogen Backbone), if the hydrogen will be transported via pipeline or road. It is assumed that road transport is the only feasible option for the transport of gaseous hydrogen, since the market availability of hydrogen ships or rail wagons is low or non-existing (Arcadis & Berenschot, 2021; Arcadis, Berenschot & TNO, 2023).

Elements of the socio-technical system that are not considered in this case study are the feedstock flows for the production of the ammonia (hydrogen, nitrogen and energy) and the end use of ammonia abroad. Also, the use, transport and end-use of the hydrogen resulting from the cracking of ammonia will not be considered, as this concerns a different chemical molecule (Grey area in Figure 4.7). However, the availability of this part of the energy system should be seen as context for the system that is considered in this case-study. As it is expected that the Netherlands will play a role in the transit of ammonia through the Netherlands for export to mainly the German industry, the transport flows of ammonia to abroad will also be considered. Furthermore, the fossil fuel-based infrastructure not related to ammonia and domestic transportation systems not involved in ammonia distribution are out of scope for this case-study.

Apart from transport modalities and infrastructure, the system also exists of (institutional) safety- and monitoring systems and financial incentives (e.g. subsidies, financing flows). The outputs of this system can, apart from the intended ammonia end-use, exist of ammonia emissions and control byproducts (e.g., nitrogen oxides), socio-economic benefits including job creation and economic growth, environmental benefits such as reduced greenhouse gas emissions, and waste materials and emissions resulting from the production and transport processes in the system.

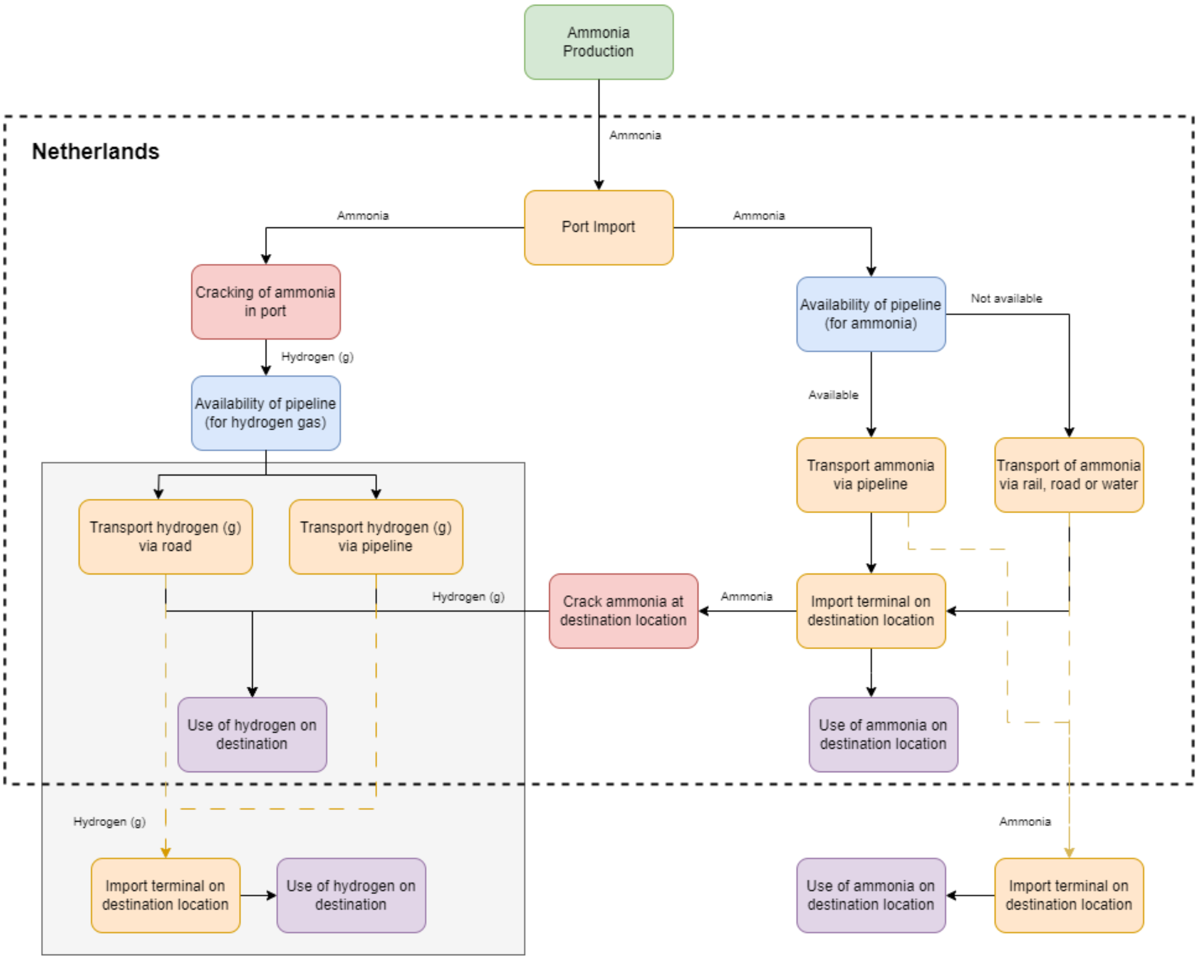

Figure 4.7: Possible production, transport and use flows of ammonia, including import and export. Green = Production, Orange = Transport and storage, Blue = a dependency, Red = Ammonia cracking, Purple = Ammonia use. Analysis of the components in the grey area are out of scope for this case-study. Figure adapted from Arcadis, Berenschot & TNO (2023).

System constraints

The socio-technical system in which ammonia is adopted faces several constraints that influence its performance. Technical constraints that are imposed on the system are dependent on the physical properties of ammonia and the technology that is available for the production, transport and use of the molecule. For example, the technological readiness level, efficiency and scalability of ammonia synthesis, transport and cracking technologies constrain the system. Important to consider for ammonia are the safety risks associated with ammonia handling and potential leaks, which can lead to emissions of nitrogen oxides (Arcadis, Berenschot & TNO, 2023). Economic constraints involve the high initial capital investment required for infrastructure development, the extra costs of producing green ammonia compared to grey production methods, and market dynamics affecting the price and competitiveness of ammonia.

Aside from technical constraints, there are also institutional constraints that affect the system, since compliance with national and international (EU) safety and environmental regulations is required. For example, from 2004 onwards, the transport of ammonia over rail and road is discouraged and legally limited by the Dutch government because the cabinet deemed ammonia too hazardous to use and transport on large scale (van Geel, 2004). Now that ammonia is in the picture to be used as hydrogen/energy carrier to support the energy transition, next to being solely used as a chemical commodity for e.g. fertilizing agricultural land, the government has planned to re-calibrate this decision. The institutional constraints that are imposed on the system are thus also subject to change. Furthermore, institutional constraints can be the lengthy and complex permitting processes for new infrastructure projects, the slow adoption of government policies and lacking incentives for the adoption of green alternatives due to the competition with (subsidized) fossil fuels. Social constraints include public acceptance and perception of risks associated with ammonia production, transport and use, ensuring equitable distribution of benefits and risks across different communities and effective stakeholder engagement in institutional decision-making processes.

Stakeholder identification and stakeholder interactions

To analyze the adoption of ammonia within the socio-technical system of the Dutch energy transition it is important to identify stakeholders and their interactions. To get an overview of the stakeholder landscape, unstructured interviews and interactions with experts and stakeholders on various occasions were used. These interviews and interactions took place at the National Institute for Public Health and the Environment (RIVM) or at attended conferences and knowledge exchange days (see Appendix B for a summary). From this preliminary stakeholder scan, it was decided which stakeholders could be interviewed for the expert interviews, which had to be conducted to continue with Step 2 of the methodological framework. During the semi-structured expert interviews, the stakeholder landscape as put forward from the unstructured interviews and expert and stakeholder interactions was validated and adjusted if the interviewees answers gave reasons to do so.

The stakeholders involved in the adoption of ammonia in the energy transition have been separated in public- and private stakeholders. As part of the conceptual investigation, also the values of the stakeholders have been conceptualized (Appendix H). Public stakeholders include the European Union, the national government on different levels, various research institutes, different regulatory authorities and local communities. Private stakeholders include the industry involved in the production, transport and use of ammonia. The role and interest of the most important stakeholders regarding the adoption process of ammonia in the energy transition will be described in this section.

Governmental Institutions

The national government plays an important role in setting the governmental boundaries for how ammonia should be used as part of the Dutch energy transition goal to become net zero by 2050. The Economic Affairs and Climate Policy (EACP) ministry is responsible for the development of policies that support the adoption of green ammonia, possibly by initiating infrastructure projects or subsidizing innovation. The Ministry of Infrastructure and Water Management (IWM) oversees the use of chemical transport modalities, ensuring that the necessary infrastructure, such as pipelines and storage facilities, is developed and maintained. Additionally, the Ministry of Justice and Security (J&S) plays a role in ensuring that all activities related to the adoption of ammonia in the energy transition comply with legal standards and safety regulations. This ministry is also responsible for crisis management in case a large-scale accident with ammonia happens. Naturally, Dutch ministries must also abide by European laws and agreements when formulating their policies, such as the free movement of goods and the climate agreement.

At the regional level, provincial- and local (municipal) governments are essential. Provinces must give accordance to permits for large-scale exploitation of ammonia, making sure that these facilities meet regional planning and environmental standards. Municipalities, on the other hand, are responsible for issuing permits for smaller production sites and overseeing local economic activities. They are most visible and approachable in the day-to-day impacts of ammonia adoption on local communities, and must ensure that local community concerns are addressed and communicated to the higher governments.

Regulatory Authorities

The government also has a more independent, regulatory role, which is executed by regulatory institutes like the environment agencies, safety regions and labour inspectorate. Environment agencies are responsible for granting environmental licenses to industry and ensuring that ammonia production, storage, and transport comply with environmental regulations. Safety regions provide advice to regional governments on safety standards and crisis management plans related to ammonia handling and transport. Fire departments work together with the safety regions to advise on and respond to incidents involving ammonia. The Labour Inspectorate conducts safety inspections to ensure that workplaces involved in ammonia production, transport and use adhere to safety regulations, protecting workers from potential hazards.

Industry Players
Next to the government and regulatory authorities, the industry plays a large role in the adoption process of ammonia in the energy transition. In the Netherlands, ammonia is currently only produced by two companies, named Yara (Sluiskil, Zeeland) and OCI (Geleen, Limburg). As this production capacity is most likely not sufficient to fulfill the demand required by the energy transition, also ammonia import from abroad is needed. This is where the transportation sector comes into play. Ports will most likely serve as key nodes for the import and export of ammonia, facilitating its movement between production sites abroad and end-users in the Netherlands (or for example Germany). The Port of Rotterdam positions itself as the future hydrogen hub of Europe, also expecting an large accompanying inflow of ammonia. Shipping companies will transport ammonia over sea. Rail companies or companies specialized in cargo-truck transport will then transport the ammonia to the chemical industry, which is in most cases the end user of the hydrogen. Then, we also have to consider the infrastructure sector, which includes companies involved in building and maintaining pipelines, storage facilities, and other essential infrastructure.

Local Communities
Local communities are the stakeholders who are impacted most in their day-to-day life by the production, transport and use of ammonia through pipelines or other modalities, such as cargo-trains passing through urban areas. Under local communities, especially the ones who currently live close to industrial facilities or rail segments used for transport of dangerous goods, there are major concerns about the adoption of ammonia in the Dutch energy transition (Bormans & Waarlo, 2024; Stil, 2024).

Research and Development Institutions
Research and development institutions, like universities and research centers as the RIVM and NIPV, focus on analyzing and monitoring the environmental and safety risks of technological innovations. This knowledge is needed to enhance the safe and sustainable adoption of ammonia in the energy transition. They collaborate with both industry and the government.

Stakeholder interactions in the adoption process
Understanding the interactions between stakeholders is necessary to analyze the ethical dilemmas in the adoption of ammonia in the energy transition. The most important stakeholder interactions, being government-government, government-industry, government-public and industry-public will be outlined in this section (Figure 4.8).

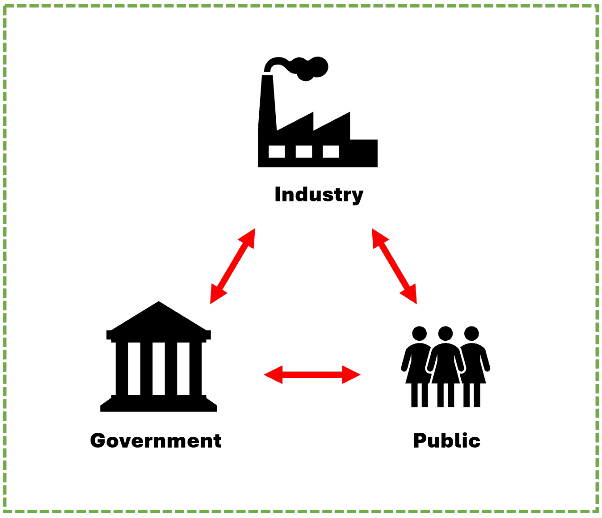

Figure 4.8: Stakeholder interactions within the socio-technical system of the Dutch energy transition, where ammonia is adopted in.

National Government - Local Government
The national government sets the vision for the energy transition and formulates policies to achieve sustainability targets through various ministries. In this process it is important to collaborate with local governments, as they are often the competent authorities for issuing permits and overseeing local economic activities related to ammonia adoption. Regular knowledge transfer between national and local governments is necessary to ensure that national policy developments are implemented at the local level and sort the intended effect. It is also important that the local governments concerns and conditions are regularly taken into account in the national policy making process.

National Government - International Governments
As the Netherlands is a small country, also cooperation with other countries is needed to drive the energy transition. This is necessary to ensure the security of supply of energy and enforcing the market position of the Netherlands in the global energy market. This can be achieved by making agreements with other countries or forging partnerships about the import or export of ammonia. For example, the construction of a pipeline connecting ports in the Netherlands with industrial sites in Germany is currently discussed between the Dutch and German governments (Arcadis, Berenschot & TNO, 2023).

Government - Industry
Government-industry collaboration also plays an important role in the safe and sustainable adoption of ammonia in the energy transition. These parties need to communicate to be able to develop the right regulatory frameworks and financial incentives. As the industry players are the ones who actually have to work with the ammonia, they can bring technical expertise and knowledge transfer to the table, as the government is often not in possession of the necessary knowledge. For example, if a pipeline for ammonia to transport from the Dutch ports to the German back-country needs to be build, public-private partnerships can drive this process and ensure that the plans are economically viable and technically feasible.

Government - Public
The government needs to involve the public in their decision-making process and needs to be transparent about the steps they take (Noordegraaf - Eelens et al., 2012). This can be cone with public consultations in policy-making, informational campaigns, and participatory decision-making processes to address local concerns and ensure that the benefits of ammonia adoption are equitably distributed. By involving the public in the decision-making process, the government builds trust under local communities. This reduces the risks on local opposition.

Industry - Public
Since the Omgevingswet (Environmental Planning Act) is in effect, companies are required to involve local communities in their decision-making processes rather than merely informing them, if they want to

get a permit for activities with potentially hazardous chemicals (van Infrastructuur en Waterstaat, 2024). This means that companies must actively engage with the public. This allows the public to participate in discussions about projects that may affect them. One of the goals of the participatory process as described in the Environmental Planning Act is that the social acceptance of energy transition project is enhanced.

Power-Interest Grid

The successful adoption of ammonia as an energy carrier in the Dutch energy transition involves a complex network of stakeholders, each with varying levels of power and interest. To understand the roles and influence of these stakeholders, a power-interest grid can be used. This grid categorizes stakeholders based on their level of power and interest. Stakeholders with high power and high interest need to be actively managed and engaged. This group includes the Ministry of Economic Affairs and Climate Policy, the Ministry of Infrastructure and Water Management, ports, the chemical industry, local communities. Stakeholders with high power but lower interest need to be kept satisfied to avoid potential opposition. These include the European Union, Authority for Consumers and Markets (ACM), the State Control of the Mines, the Labour Authority, and the Telecom Agency. Stakeholders with lower power but high interest need to be kept informed to maintain their support and engagement. This group consists of provinces, municipalities, environmental organizations. Lastly, stakeholders with low power and low interest need minimal effort but should still be monitored. This includes international organizations like the OECD and JRC and (international) universities.

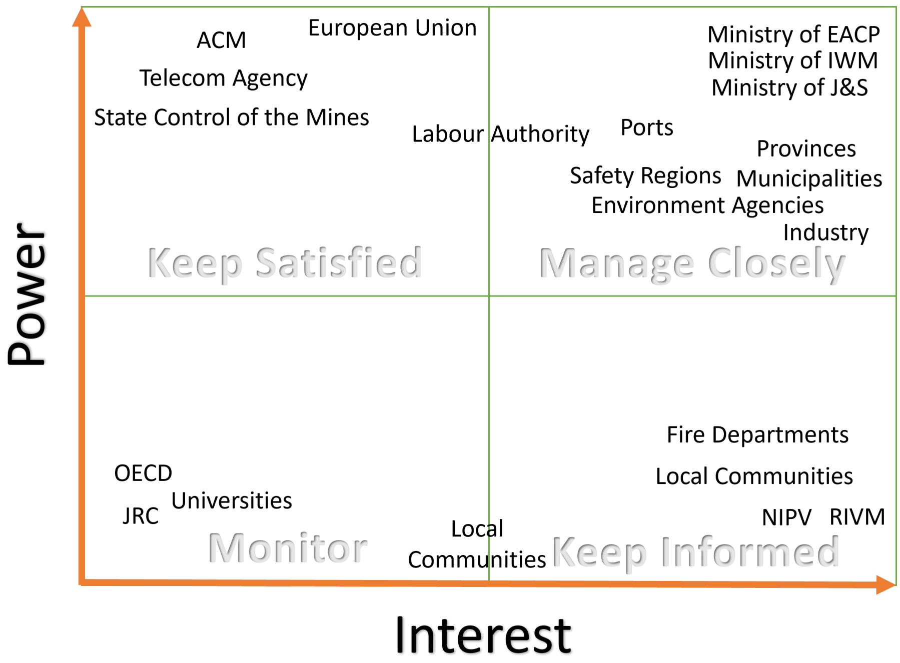

Figure 4.9: Power-Interest matrix of stakeholders identified concerning the adoption of liquid hydrogen carrier molecules in the Netherlands. Industry = Ammonia Producers and Users, Infrastructure and Transportation sector.

4.2.2. Step 2: Identifying Values and Value Conflicts

Value identification

With the socio-technical system where ammonia is adopted in delineated, the focus of the case-study was then moved to empirical value investigation part of the framework, which started with the value identification as part of the empirical investigation.

Value identification was achieved through qualitative analysis of 11 expert interviews encompassing a wide array of stakeholders, including industry experts, policymakers, and researchers. These experts were chosen to represent the stakeholder landscape as sketched in the previous framework step.

Qualitative content analysis was employed to extract value-laden statements from the interviews. A deductive codebook, inspired by previous research into ethical dilemmas in the energy transition, was utilized as starting point in this process. By also making use of inductive coding, the process allowed for making additions to the codebook if new values emerged from the qualitative data.

From the thematic analysis, 11 values which play a role in the debate around the adoption of ammonia were identified. Of these values, seven were mentioned in every interview (Figure 4.10). These values can be seen as the major values which play a role in the adoption process of ammonia in the Dutch energy transition. The other four identified values (Affordability, Reliability, Security of Supply and Accountability) can be seen as minor values which play a role in the adoption process of ammonia in the Dutch energy transition. These values, their conception, the level on which the values play a role and the affected stakeholders will be explained in this section. Also an example of the value-laden statement where the value is identified from is given. These statements often already show the value conflict at play. See Appendix G for the full results of the thematic analysis.

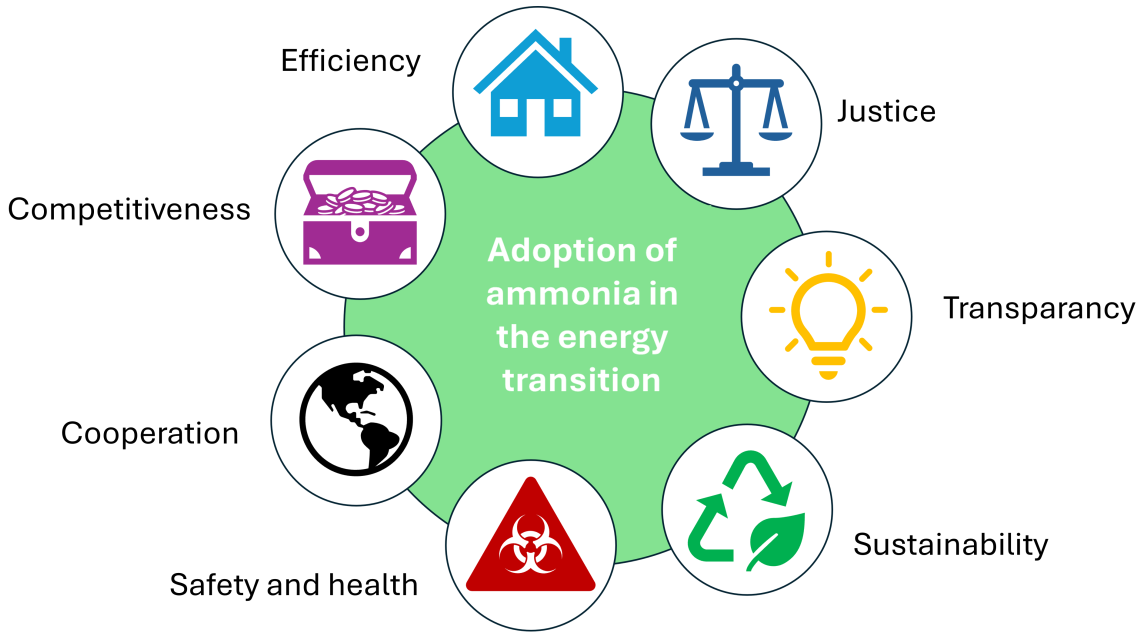

Figure 4.10: Values which were identified to play a role in the adoption process of ammonia the energy transition. Apart from the 7 values as shown in the figure, also the values Affordability, Reliability, Security of Supply and Accountability were identified. These were not included in this figure because they only played a relatively minor role in the interviews compared to the values shown.

Environmental Sustainability

Since we are analyzing the adoption process of ammonia in the energy transition, it was expected that the value *Environmental Sustainability* would play a big role. This was indeed the case, as it came back in almost all interviews. The value of *Environmental Sustainability* plays a role on the local, national and international level, and mostly affects local communities, companies, the government and environmental organizations. The conception of the value was however different for different interviews. The possible emissions of ammonia or nitric oxides (NOx) by production, transport and use of the chemical were deemed problematic, especially in connection to the Dutch nitrogen crisis. This quote was taken from an interview with an industry expert:

> *For the Duch nitrogen problem, there are actually two aspects of ammonia that are problematic. There are nitrogen oxides that arise from transport or combustion, but also naturally by possible emissions of ammonia in a production process or in storage or a transport system. So, you absolutely want to prevent ammonia from leaking.* - Policy Advisor

Environmental Sustainability was also mentioned with a negative conception concerning the way imported ammonia is produced. There is the fear that currently, investments and infrastructure projects are initiated because there is a promise of green ammonia, but it is not clear if the imported ammonia will anyway soon be green due to technological readiness of ammonia production technology and the cheap (and subsidized) fossil fuels in the countries were grey ammonia is produced on large-scale. Because the end-goal of the energy transition is of-course to become net-zero as a country, this can become problematic. This is reflected by two quotes of different policy advisors:

> *Because yes, everything is naturally an ethical dilemma about if you find it responsible to possibly participate in greenwashing as a government? Of course, everything you do must really lead to improving the environment, otherwise you wouldn't make such a whole transition away from fossil gas* - Policy Advisor

> *When I ask ammonia producers: When do you think there will be green ammonia? So, that means fully made from solar or wind energy. When do you think you can deliver that? Then they say: After 2040. And so the concern is that we ultimately maintain the existing oil industry (abroad) and that sustainability is somewhat lost out of sight due to economic interests.* - Policy Advisor

Safety and Health
As was also expected due to the hazardous properties of ammonia, the value of *Safety and Health* played a prominent role in all interviews. Safety concerns mostly affect local communities, or people who are working with or transporting ammonia on a local level. However, since the government has the obligation to look out for the safety and health of the public, the consideration of this value also has consequences on the national level. The conception of the safety and health of the production, transport and use of ammonia in the energy transition as explained by the interviewees was however again quite different from interview to interview. Some interviewees were confident that the health and safety risks of handling ammonia on large-scale could be handled without problems, while others were not so positive. The external safety of various transport modes, like pipeline and rail, was perceived fairly positive from a technical viewpoint by researchers, policy advisors and an industry player:

> *As long as the outflow is not extremely large, then I think you can install a pipeline, but it must stay within reasonable limits.* - Researcher Industrial and Environmental Safety

> *I am convinced that the rail is a safe modality for the transport of ammonia.* - Policy Advisor

> *Well, and if you look at the chance, it's 10 to the power of -8 or so (failure frequency), so that's once in 10 million years that it goes wrong. Yes, then that is acceptable.* - Consultant Ammonia Terminals

This last quote highlights the ethical debate about to what extent civilians can be subjected to external safety risks, which will be further analyzed in the Discussion Chapter (Chapter 5) The conception of the potential effects and crisis management perspectives if an accident happens during the production, use and transport of ammonia are perceived negative:

> *Ammonia is just terribly toxic, really abnormally toxic. Breathe it in in a reasonable concentration and you're completely done for.* - Safety Consultant

> *No, there's almost no action perspective in the event of a disaster with ammonia.* - Policy Advisor

There are also concerns that there is not enough knowledgeable personnel available to deal with the large amounts of ammonia that are expected to be transferred to the Netherlands:

> *A concern for many parties is: How do you ensure that there is knowledgeable and skilled personnel to operate those terminals. You don't want accidents to happen with such a toxic substance due to staff incompetence.* - Port Manager

Efficiency
Because the energy transition needs to be made as fast as possible and with the least amount of resources used, the value *efficiency* also came back multiple times. The conception of the value of *efficiency* depended on the discussed use-case for ammonia in the energy transition during the interviews. When analyzing the prospects of using ammonia as energy carrier, there are negative conceptions about the energy-loss involved in coupling- and decoupling hydrogen to ammonia:

> *Because with the use of ammonia as an energy carrier, you lose a lot of energy through all those conversions. So we have to be careful not to be led by, actually maintaining the current industry, which actually makes energy unnecessarily expensive because there are so many actions and conversions involved.* - Policy Advisor

This policy advisor was concerned about the push to market of ammonia by the existing grey ammonia producers, while it is energy-wise not efficient according to him. The prospects for using ammonia as an energy carrier are conceived as more positive:

> *Yes, on all sides, the market is screaming for hydrogen or ammonia. I expect that in the future it will mainly be ammonia because it's just much easier. Otherwise, you have to go back to hydrogen. Why would you do that if you can burn it directly?* - Consultant Ammonia Terminals

The value of *Efficiency* also came back in a different, unexpected, way. As the energy transition requires a lot of new energy infrastructure, there are problems foreseen in the efficient spatial planning in the Netherlands. This occurs for example in ports, were space to perform activities with hazardous chemicals is limited, but also in more populated areas where ammonia has to be transported through. Here, local governments face problems in balancing residential building plans and the production, transport or use of hazardous chemicals.

> *We just have the problem that there is a lot of scarcity in space. The vast majority of the port is already in use or there has been a cross marked for a company that has already paid for that ground.* - Port Manager

The value of efficiency thus plays a role on national level, if the energy efficiency of using ammonia for the energy transition is concerned, but plays at a more local level regarding spatial planning efficiency.

Competitiveness
Competitiveness concerns the more economic side of the adoption of ammonia in the energy transition, as the definition of the value was formulated as that the adoption of ammonia in the energy transition should offer an economic advantage. This means that the intended use-case for ammonia should be cost-competitive in comparison with other alternatives. For example, green ammonia should be able to compete with grey ammonia in terms of price as a condition for its large-scale adoption. Regarding the use of ammonia as energy carrier, it should be competitive to use (green) ammonia in comparison to other (green) energy carriers. This value mostly plays a role on the national and international level, and affects mostly the industry players. In terms of competitiveness, the position of the Netherlands regarding the governmental decision on the desirability of ammonia in comparison to other countries came back multiple times. An example statement of this was given by a Port Manager, who had the opinion that the government was behind on making the decision to import and use ammonia in the energy transition, as the world market has long ago accepted ammonia to play a role in the energy transition:

> *My feeling is now that actually making the choice not to want ammonia is a bit of a station passed. The whole world has devised ammonia as a (temporary) solution. Unless you want to completely sideline yourself as the Netherlands, you must also deal with ammonia. And so it is more about how that discussion goes, how then? How are we going to do ammonia?* - Port Manager

A fear of a policy-maker observed during the interviews was that the adoption of ammonia currently is too much prize driven, loosing the initial sustainability goals and safety concerns out of sight. He expressed the fear that currently, investments are made in ammonia import, transport and use infrastructure, while this ammonia is not produced green, and still imposes safety and health concerns.

> *And the first thing people then think is, okay, what's the alternative and how can we play a role in it? And they actually see ammonia as an option first now. And that is price-driven.* - Policy Advisor

Affordability
Connected to the value of *Competiteveness* is the value of *Affordability*. Industry players indicated that

for them, price and return on investment is leading in the choice of adoption of an energy carrier like ammonia:

> *If it is much more expensive than other things, it makes no sense to even look at the rest* - Market Expert

Policy advisors were not positive about the affordability of ammonia because of its energy intensive production process and many conversions that are needed for use as an energy/hydrogen carrier:

> *You must provide subsidies because it is too expensive.* - Policy Advisor

Justice
What also came back as an important value in all interviews was the value of *Justice*. *Justice* was mentioned in two different conceptions, being procedural justice and distributive justice. Procedural justice focuses on the processes that ensure all stakeholders, especially the public, are involved in decision-making in a transparent manner. A Port Manager mentioned procedural justice by referring to the implementation of the new Environmental Planning Act (Omgevingswet):

> *The Environmental Planning Act (Omgevingswet) went into effect on January 1st and it says, you must not only communicate but also participate. So also in safety investigations for new projects: Go there to map out what the concerns of the worried citizens and other parties are. So we invite them and they are really allowed to look into the research and think along, like what questions need to be answered by us. This is done so that we fully involve them, including what then comes out as a conclusion. With the goal that we are all at the same flying height in terms of information. It ensures that the involvement of all those parties is much better and that is the first step towards, hopefully, consensus. That takes a lot of energy, but that is really necessary.* - Port Manager

Similarly, a Policy Advisor stated the importance of transparency and public understanding in procedural justice:

> *I am very much in favor of a government that is being transparent about accepting certain risks and explaining that. And I also get the impression that citizens really understand that, right? Sure, if you ask citizens if they want it to be safer? Yes, they want it to be safer, but if you just present the trade-off you have to make, then they are quite capable of following and understanding such a trade-off.* - Policy Advisor

Distributive justice, on the other hand, concerns the equitable distribution of benefits and burdens among different stakeholders. It questions whether the risks and advantages of adopting ammonia are fairly shared, especially among affected local communities. For example, both a Policy Advisor and Research expert showed concerns about imposing risk on citizens:

> *Can you really impose that burden on the citizens in the Netherlands, with such a substance as ammonia and the associated risks in terms of external safety?* - Policy Advisor

> *Look, we're going to lay down a pipeline across the Netherlands soon and the large companies will benefit a lot from it because it has to be profitable. That's fine, but those who suffer from it are the people who live alongside it, of course.* - Researcher Industrial and Environmental Safety

These statement show the possible imbalance between the economic benefits gained by large companies and the risks and concerns faced by local communities. The debate around the value of justice revolves both at the national and the local level, as it affects both the government and local communities as stakeholders. Distributive justice was also mentioned on the international level, where the question was raised if it would be responsible to import ammonia from countries where there is already a water shortage:

> *If you want to import ammonia on a large scale, naturally, you will be doing that from certain countries that may have different norms and values than the Netherlands, right? How do you deal with that? That is something that, of course, needs attention. If you want to import ammonia from countries where there is already a shortage of water, you should ask yourself if that is just.* - Policy Advisor

Transparancy
Connected to the value of *Justice* is the value of *transparancy*, which plays a role nationally and locally and affects the government, industry players and local communities. To support the feeling of procedural justice amongst local communities and industry, the process of letting citizens and industry participate in policy decision-making requires transparancy:

> *As long as you make it safer than it is now or just as safe, then I think you can sell a good story. But it is important that you involve the citizens and not that you lay down the pipe and then get all kinds of trouble afterward because then you are struggling for much longer.* - Researcher Industrial and Environmental Safety

> *But I do see that the ministry is very open and willing to share that information transparently. They are also open about their policy developments and dilemmas and share information at an early stage. Not necessarily only when everything is already decided, but also during the development phase.* - Energy Transition Consultant

Accountability
The value of accountability was also identified in one interview. The value was mentioned concerning the question which stakeholder bears the responsibility and accountability if an accident with ammonia happens.

> *Ammonia is naturally a toxic substance, so you really have to handle it very carefully, which is why you are always a BRZO/Cevezo (Major Accident Hazards) company. So, that carefulness. Yes, that affects everything, of course, maintenance, how you manage such a terminal. You must have a proper management system and yes, everything that actually belongs to a BRZO company. That carefulness is clearly reflected in our company. In the state of the equipment, how we manage the terminal. Yes, everything really.* - Consultant Ammonia Terminals

Cooperation
The value of *Cooperation* was also mentioned multiple times. Within the energy transition, it is a process of trial- and error which choices need to be made by the government and which room can be given to the industry. This was mentioned by a Research Expert, who had the opinion that the government should take more initiative in setting the boundaries for the adoption of ammonia in the Dutch energy transition:

> *It is an interplay between market and government. The government indicates what is possible and it is up to the market whether they will actually utilize that space or not.* - Researcher Industrial and Environmental Safety

From the thematic analysis, it was also clear that international cooperation is also detrimental in the adoption of ammonia in the energy transition. It was observed that this is especially the case when looking at the possible ammonia transportation infrastructure which should connect Germany with the Netherlands:

> *We can of course build infrastructure towards Germany, but it is important that there is a buyer on the other side of the border, otherwise you get another Betuwe line drama. So coordination with Germany is also very important here. Yes.* - Researcher Industrial and Environmental Safety

Reliability
The value of reliability emerged as a concern in the discussions surrounding the adoption of ammonia as an energy carrier. Reliability refers to the assurance that the chosen technology will perform consistently and remain relevant over time. Technological lock-in is a situation where a technology becomes dominant, making it difficult to adopt alternative solutions in the future. This could be sub-optimal with a hazardous chemical like ammonia:

> *If we now opt for ammonia, are we not stuck with a lock-in and stuck for 20 years to a stream of ammonia transport that we, let's be honest, would rather not have.* - Port Manager

> *That it is already assumed in some conversations that ammonia is the solution. Which means that there is actually no freedom anymore to say, what are the alternatives? Can we*

> *also do it in new and different ways?* - policy Advisor

Security of Supply
The value of *security of supply* was only mentioned in one expert interview. This concerned the dependency on Russian gas.

> *On the other hand, when we were doing this, there was also a very intense geopolitical discussion going on: We want to get rid of Russian gas, so that discussion was also very intensely fought, which meant that for some time more natural gas was being imported from other countries, but also indeed, how can we ensure that we become less dependent on less friendly countries, also in the area of the energy transition, right? Thus, spreading the chances over many different countries where ammonia was made, for example with all sorts of covenants and contracts from Oman to Chile to Morocco and who knows where.* - Safety Consultant

Constructing value hierarchies

With the values that play a role in the debate around adoption of ammonia identified, the value hierarchy as proposed by (van de Poel, 2013) could be constructed. Of the 11 identified values, the seven values Safety and Health, Competetiveness, Affordability, Environmental Safety, Efficiency and Justice came back in almost all interviews and were therefore deemed as the most important values in the debate around the adoption of ammonia in the energy transition. For the value hierarchy construction and the value conflict identification therefore only these seven values will be considered. This was also decided due to the limited time that was available for this research project.

From thematic analysis of the interview data, it was noticed that the interviewees did mainly reflect on norms - and provided arguments around that. This was also observed in Dignum et al. (2015), of which a visual conception is shown in Figure 4.12).

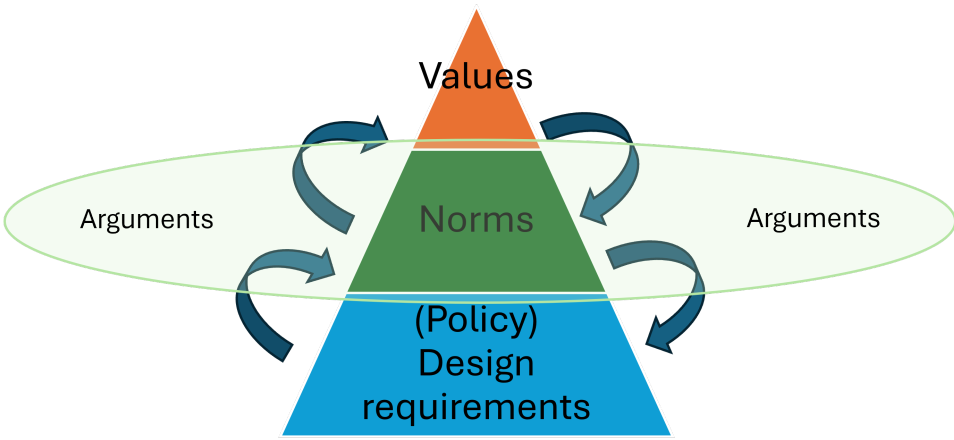

Figure 4.11: Value hierarchy and arguments (adapted from Dignum et al. (2015)).

However, using these interview questions, interviewees were not able to reflect on technical design requirements properly, This was partly because the interview questions focused on the adoption of ammonia in the whole energy transition, not specifying a technological artifact were technological design requirements could be specified for. For the broader adoption of ammonia in the energy transition, institutional design requirements could still be given. It was therefore decided to only construct a value hierarchy up until the level of norms about how the adoption process of ammonia should be performed.

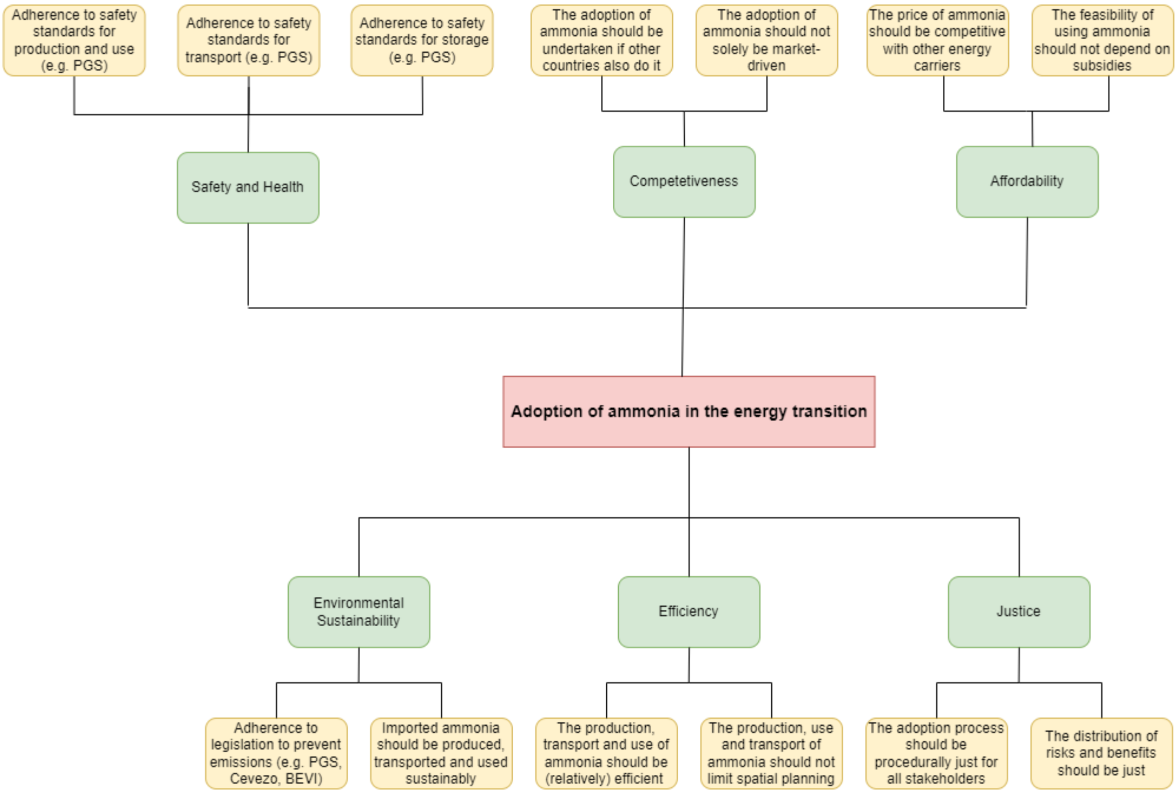

Figure 4.12: Value hierarchy showing values and norms which play a role in the debate around the adoption of ammonia in the Dutch energy transition. Green = Value, Yellow = Norm.

Value conflict identification

By comparing norms associated with different values in the value hierarchy, several potential value conflicts could be identified. Not all value conflicts were articulated literally by the interviewees. The interpretation and reflection of the author of this work based on the expert interviews also contributed to the identification of the value conflicts.

Safety and Health vs. Justice, Affordability, Efficiency & Environmental Sustainability

The value of Safety and Health is, or can be, in conflict with various values in the adoption of ammonia in the energy transition (Figure 4.13).

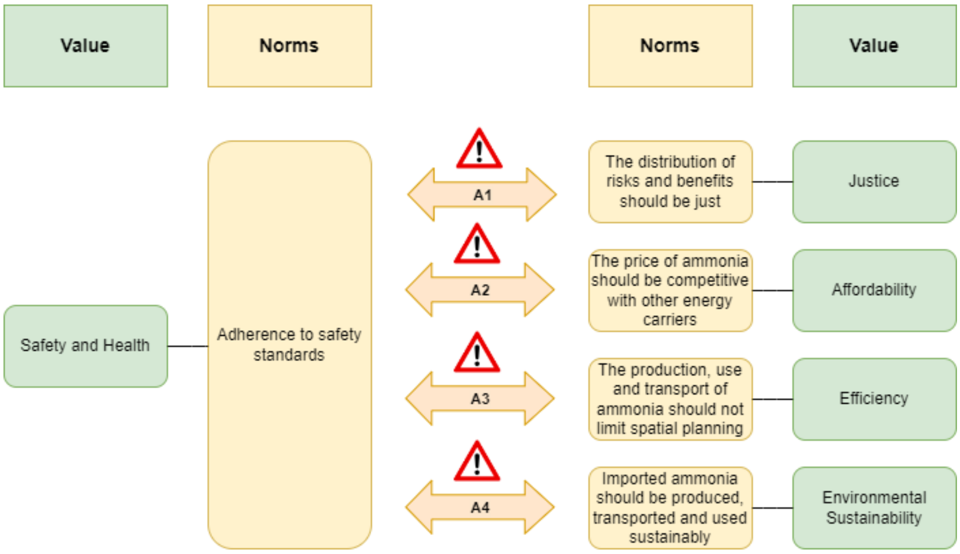

Figure 4.13: Value conflicts between Safety and Health and Justice, Affordability, Efficiency and Environmental Sustainability.

Rigid adherence to safety standards may conflict with the equitable distribution of risks and benefits between local communities, the government and industry (Figure 4.13, A1). The value conflict between the values of Safety and Health and Justice shows the ethical dilemma that a government faces concerning how much safety and health risk can be imposed on citizens in favour of the energy transition:

> *Involving the local community in safety discussions is crucial, but we must also consider the fairness of imposing certain risks on them while benefiting industries located elsewhere.* -Policy Advisor

Furthermore, ensuring high safety standards can increase costs, which could bring the values of Safety and Health and affordability in conflict (Figure 4.13, A2). Here the cost-effectiveness of safety measures comes into play. If the safety requirements of ammonia production, transport and use are too stringent, ammonia could be not competitive with other energy carriers. The observed underlying ethical dilemma revolves around to what extent safety should be ensured by the government. Prioritizing safety can also compromise spatial planning, especially in the Netherlands, where space is scarce. This value conflict for example plays a role in local communities where rail transport of hazardous chemicals goes through. Local governments then have to decide to what extent it is safe enough to build next to the track, as an accident could happen with the trains on the track carrying e.g. ammonia. In the Netherlands, certain safety standards are put in place to protect citizens from risky activities, like the pollution of the chemical industry and the transport of dangerous substances. These safety standards work fine most of the times, but can start to pinch due to the spatial planning challenge that the Dutch government faces in the energy transition (Figure 4.13, A3). Here, choices need to be made between offering room for energy transition initiatives like the adoption of ammonia for several purposes, and building houses:

> *And then you see that the safety issue and the issue of spatial planning clash with each other. The Rotterdam port is still full of fossil industry, right? That also has risks, but it often involves fire and explosion and those kinds of things, so for the surrounding area that is a bit further away, there is often not a direct risk. Sometimes something does go wrong, which then leads to odor nuisance and such, but not on the scale of toxic clouds drifting over a city or something (which can happen with ammonia)* - Policy Advisor

Balancing the acceleration of the energy transition with safety concerns can also be a value conflict (Figure 4.13, A4). As the climate crisis imposes long-term safety and health risks on people, the government should balance the health and safety risks on the short-term (e.g. caused by ammonia transport and use) with climate crisis effects on safety and health on the long-term:

> *Yes, there is a very small chance that you will have one major ammonia disaster, but what is the alternative? If you do nothing, then maybe global warming will accelerate even more.*

Yes, and that can also lead to many casualties. So there is definitely a dilemma there. - Researcher Environmental and Industrial Safety

Environmental Sustainability vs. Justice and Competitiveness
The value of Environmental Sustainability can be in conflict with the values of Justice and Competitiveness (Figure 4.14).

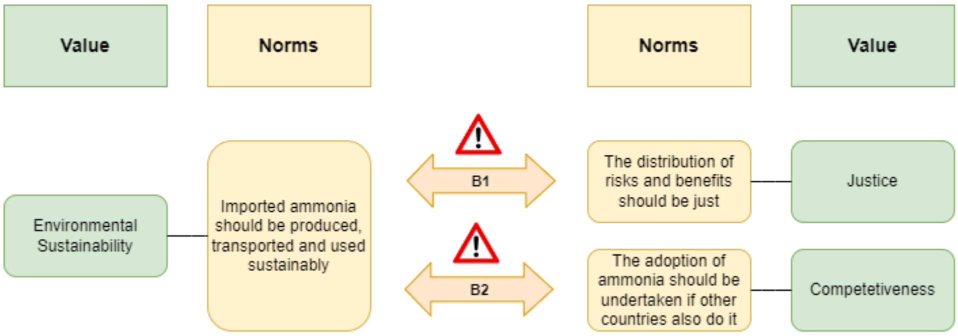

Figure 4.14: Value conflicts between Environmental Sustainability and Justice and Competitiveness.

Ensuring that the imported ammonia is actually green, and does not stay grey, can conflict with distributive justice. This can for example be the case if green ammonia is imported out of a country where water is limiting. This means that we can use green ammonia here, but maybe the local communities there suffer from a lack of drink-water availability due to the high water demand of green ammonia production. (Figure 4.14, B1).

Furthermore, it can be challenging to unify competitiveness and environmental sustainability in the energy transition (Figure 4.14, B2). Currently, grey alternatives (e.g. fossil fuels) often can be produced much cheaper than green alternatives (e.g. green ammonia). This is why governmental choices have to be made between choosing the most sustainable alternatives but still provide the market with enough incentive to invest in these technologies. This value conflicts is highlighted by the quote below:

The market will favor cheaper, grey ammonia unless strict regulations are in place to support green ammonia. - Industry Player

Efficiency vs. Justice
Procedural justice in the adoption of ammonia in the Dutch energy transition can conflict with the value of efficiency (Figure 4.15).

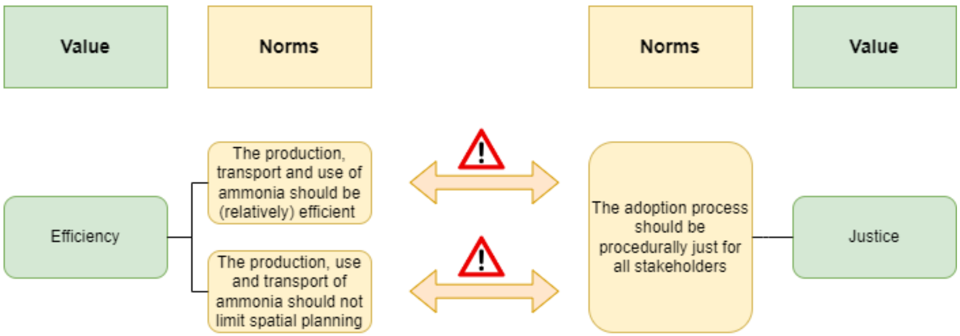

Figure 4.15: Value conflicts between Efficiency and Justice.

Being transparant about decision-making as government towards the public can increase the support for energy transition projects. However, too much participation could also hinder the effectivity of the energy transition, hereby slowing down the energy transition:

Procedural justice means involving communities in every step, but this can slow down the project timelines significantly. - Industry Player

4.2.3. Step 3: Classifying and addressing value conflicts

With the values and value conflicts that play a role or could potentially play a role in the debate around the adoption of ammonia in the energy transition established, we could move on to the third step of the methodological framework, which aimed to provide handles classify and address value conflicts. This can be seen as the technical investigation part of this case study. As proposed in the methodological framework, the same workflow to classify value conflicts as in Wildt (2020) was followed in this work. This means that first, the resources to address the value conflicts and resulting social acceptance issues were analyzed.

Resources required to deal with value conflicts

To derive the resources which are needed to address the value conflicts, technical design requirements, institutional design requirements, and stakeholder interactions were defined which are currently missing in the socio-technical design of the energy system, based on input from the expert interviews (Table 4.1). In these interviews, it was asked which technical design requirements, institutional design requirements and stakeholder interactions are missing in the current adoption process of ammonia in the Dutch energy transition, and how these could address the sketched value conflicts.

Technical Design Requirements

In the interviews, not much technical design requirements were mentioned by the interviewees. This could be caused by the fact that the interview questions did not specify specific parts of the socio-technical system of ammonia adoption, as also discussed in subsection 4.2.2. Therefore, the technical design requirements that could potentially be put in place to address value conflicts are not given in this work.

Institutional Design Requirements

Institutional design requirements which can be put in place to address the identified value conflicts involve establishing regulatory frameworks that support the safety, efficiency and justice of ammonia adoption in the Dutch energy transition. For the conflict between safety and health versus justice, (more stringent) regulatory frameworks and standards for ammonia safety could be developed. In these regulatory frameworks, equitable risk and benefit distribution across different geographical regions and stakeholder groups should be taken along.The development of regulatory frameworks to ensure safety and health should be balanced with efficiency, as these frameworks should be cost-effective and not hinder the energy transition. Also choices need to be made between the efficiency of spatial planning and safety and health. The accepted risks levels regarding the use and transport of hazardous chemicals could be adjusted in certain scenarios to give room for tailor-made policy by the local governments. In the case of safety and health versus environmental sustainability, regulations must ensure that ammonia production, transport and use meet both environmental and safety standards. This could be achieved by enforcing standards on imported ammonia, so that it is known if the imported ammonia is produced with a green or grey production process. This will promote a level playing field for green ammonia. Furthermore, as a general institutional design requirement, the expert interviews made clear that a clear vision from the government on the ethical desirability of adopting ammonia in the energy transition is needed. In this vision, the government should specify the intended use for green ammonia in the energy transition (e.g., substituting grey ammonia, as an energy carrier, or as a hydrogen carrier), as well as reflect on the ethical dilemmas that the government faces and how it makes decisions in that regard.

Stakeholder interactions

Creating stakeholders interactions, or enhancing existing interactions, can be used to complement the required institutional design requirement in addressing value conflicts. For the conflict between safety and health versus justice, engaging with local communities to address their safety concerns and perceptions of unfair risk distribution is important. The government should be clear about its vision on the energy transition, available technological alternatives that can be utilized, risks associated with these alternatives, and the choices the government makes concerning certain value conflicts (e.g., safety and health risk vs. accelerating the energy transition). This helps create social acceptance and addresses value conflicts between safety and health, justice, and the efficiency of the energy transition.

Strong collaboration between industry and government is necessary, as the industry possesses the needed technical expertise, while the government can provide regulatory guidance and boundaries. If needed, the government can also assist the industry in making the energy transition by for example subsidies. Companies and local governments should communicate with regulatory authorities to ensures compliance with safety standards. In the case of safety and health versus affordability, transparent communication with the public about the costs and benefits of safety measures can help gain social acceptance. For safety and health versus efficiency, collaborating with local authorities to address spatial planning and safety concerns is important, as is involving industry players. For environmental sustainability versus justice, the government should engage with communities where green ammonia will be imported from to ensure that their concerns are addressed. Simultaneously, the government could work on inclusive climate policies that promote environmental justice. Finally, for efficiency versus justice, transparent communication from the government with local communities about the benefits and risks of ammonia adoption and the energy transition is necessary to gain their support and involvement.

Table 4.1: Resource requirements needed to adress value conflicts

Value Conflict	Institutional Design Requirements	Stakeholder Interactions
A1 Safety and Health - Justice	- Regulatory frameworks and standards for ammonia safety.	- Engage with local communities to address their safety concerns and perceptions of unfair risk distribution.
	- Policies to ensure equitable risk/benefit distribution across different geographical regions or stakeholder groups.	- Collaborate with regulatory authorities to ensure compliance and effective enforcement of safety standards.
A2 Safety and Health - Affordability	- Regulatory frameworks and standards that allow for cost-effective safety policies.	- Transparent communication with the public about the costs and benefits of safety measures. - Involve industry stakeholders to find a balance between safety and cost-effectiveness.
A3 Safety and Health - Efficiency	- Policies that streamline the permit process while maintaining safety standards.	- Collaborate with local authorities to address spatial planning and safety concerns. - Involve industry stakeholders to find a balance between safety and spatial planning.
A4 Safety and Health - Environmental Sustainability	- Regulations to ensure ammonia production and transport meet environmental and safety standards.	- Involve environmental groups and local communities in decision-making processes.
B1 Environmental Sustainability - Justice	- Policies to ensure fair distribution of environmental benefits and burdens. - Policies for compensating communities that bear disproportionate risks.	- Engage marginalized communities to ensure their concerns are addressed. - Work with policymakers to develop inclusive policies that promote environmental justice.
B2 Environmental Sustainability - Competitiveness	- Regulations to ensure imported ammonia meets environmental standards.	- Collaborate with international partners to align sustainability standards.
C1 Efficiency - Justice	- Policies to ensure procedural justice in the adoption of ammonia technologies.	- Transparent communication with local communities about the benefits and risks of ammonia adoption and the energy transition.

Potential acceptance issues

From a policy-making perspective, it can be interesting to also shine a light on the potential social acceptance issues that can arise if value conflicts are not addressed, as these may hinder the adoption process of ammonia in the energy transition (Table 4.2). This was done by categorizing the social acceptance issues which could potentially result from the value conflicts in the three categories as proposed by Wüstenhagen et al. (2007) being: Socio-political acceptance, market acceptance and community acceptance. Socio-political acceptance issues can arise when policy decisions appear to favor certain geographical regions or stakeholder groups over others. This can create perceptions of inequality under the public and lead to political resistance. For example, the conflict between safety and health versus justice can result in socio-political acceptance issues if the distribution of risks is seen as unjust. This can hinder policy development. Community acceptance issues can occur if the local population's response to the adoption of new technologies or technology projects is negative. If the perceived risks or benefits of ammonia adoption are unevenly distributed, local resistance may be faced. This can lead to protests and opposition from local authorities. Market acceptance issues concern the economic viability and attractiveness of ammonia for the intended use, so that the market also sees an incentive to invest. Market players might resist adopting ammonia if it is not clear what the benefits are or if the vision of the government concerning ammonia adoption is not clearly communicated. Furthermore, concerns about technological lock-in can decrease investments as stakeholders may fear being stuck with an undesirable technology for an extended period.

Table 4.2: Illustration of potentially resulting acceptance issues.

#	Value conflict	Socio-political acceptance issues	Community acceptance issues	Market acceptance Issues
A1	Safety and Health - Justice	- Policy decisions could favour certain geographical regions/stakeholder groups over others. - Lacking regulatory preparedness	- Local resistance if perceived risks or burdens are unevenly distributed - Resistance from local authorities - Protests on local level	- Difficulty in market penetration in regions that perceive ammonia use and transport as unjust. - Market players may not value safety and health as much as is needed
A2	Safety and Health - Affordability	- Debates over the cost-effectiveness of safety measures		- Low adoption rate if ammonia transport and use is not cost effective due to stringent safety measures - Limited investments by industry
A3	Safety and Health - Efficiency	- Debates over (effective) spatial planning and safety and health risks - Rejection of permits by legislative authorities - Lack of political backbone	- Community concerns about potential risks from prioritizing (spatial) efficiency over safety	- Resistance from market players who may need to compromise on efficiency to enhance safety measures. - Limited investments by industry - Path dependency leading to the lock-in of a socially undesirable technology
A4	Safety and Health - Environmental Sustainability	- Balancing the acceleration of the energy transition with safety concerns	- Safety concerns from the public could slow-down the energy transition	- Companies will not invest if there are too much safety risks
B1	Environmental Sustainability - Justice	- Ensuring that the risks and benefits of the energy transition are fairly distributed	- Potential opposition in areas where communities feel marginalized or overlooked by governmental institutions	- Difficulty in ammonia adoption in lower-income or marginalized areas that might not see the direct benefits of the energy transition
B2	Environmental Sustainability - Competitive-ness	- Debates around if the imported ammonia will actually be green, or will long stay grey, as it is now		- Market barriers if the adoption ammonia is not perceived as beneficial in the energy transition - Path dependency leading to socially undesirable technologies
C1	Efficiency - Justice	- Debate about how much local communities need to be involved in the desirability of ammonia adoption	- The public can oppose decisions by the government if they are not transparently informed	- Market players may not have sufficient eye for the procedural justice of local communities

Value conflict classification

By classifying the value conflicts based on the resources required to deal with the value conflict, the potentially resulting social acceptance issues from not dealing with the value conflict and the resolvability potential of the conflict, dealing with the value conflicts can be prioritized (Figure 4.16). It must be noted here that this classification is made based on the authors judgement, and serves to give a rough idea about how the identified value conflicts can be prioritized.

Severity of Acceptance Issues

The severity of acceptance issues varies across different value conflicts. For instance, the conflict between safety and health versus justice (A1) is marked by high severity due to the potential for local community resistance. Similarly, the conflict between safety and health versus environmental sustainability (A4) also has a high severity of potentially resulting acceptance issues, as public safety concerns by local communities can slow down the energy transition. In contrast, the conflict between environmental sustainability and justice (B1), which concerns the just import of green ammonia from countries abroad, is categorized as low severity because this does not affect Dutch stakeholders as much as the other value conflicts.

Degree of Resolvability

The estimated degree of resolvability of each value conflict indicates how feasible it is to address the conflict through various measures. For instance, the conflict between safety and health versus affordability (A2) is resolvable, as financial incentives and cost-effective safety technologies can relatively easily address this issue. Similarly, the conflict between environmental sustainability and competitiveness (B2) is relatively resolvable. On the other hand, the conflict between safety and health versus (spatial) efficiency (A3) has a low degree of resolvability, as space constraints in the Netherlands pose a challenge in balancing housing and industrial needs.

Required Resources for Resolution

The required resources for resolving each value conflict can also vary drastically from conflict to conflict. High resource requirements are expected for fundamental conflicts such as safety and health versus justice (A1), where investments in community engagement and regulatory improvements can be time-consuming and expensive. The conflict between safety and health versus environmental sustainability (A4) also potentially requires high resources, because the debate on balancing community safety and health and accelerating the energy transition is not an easy one.

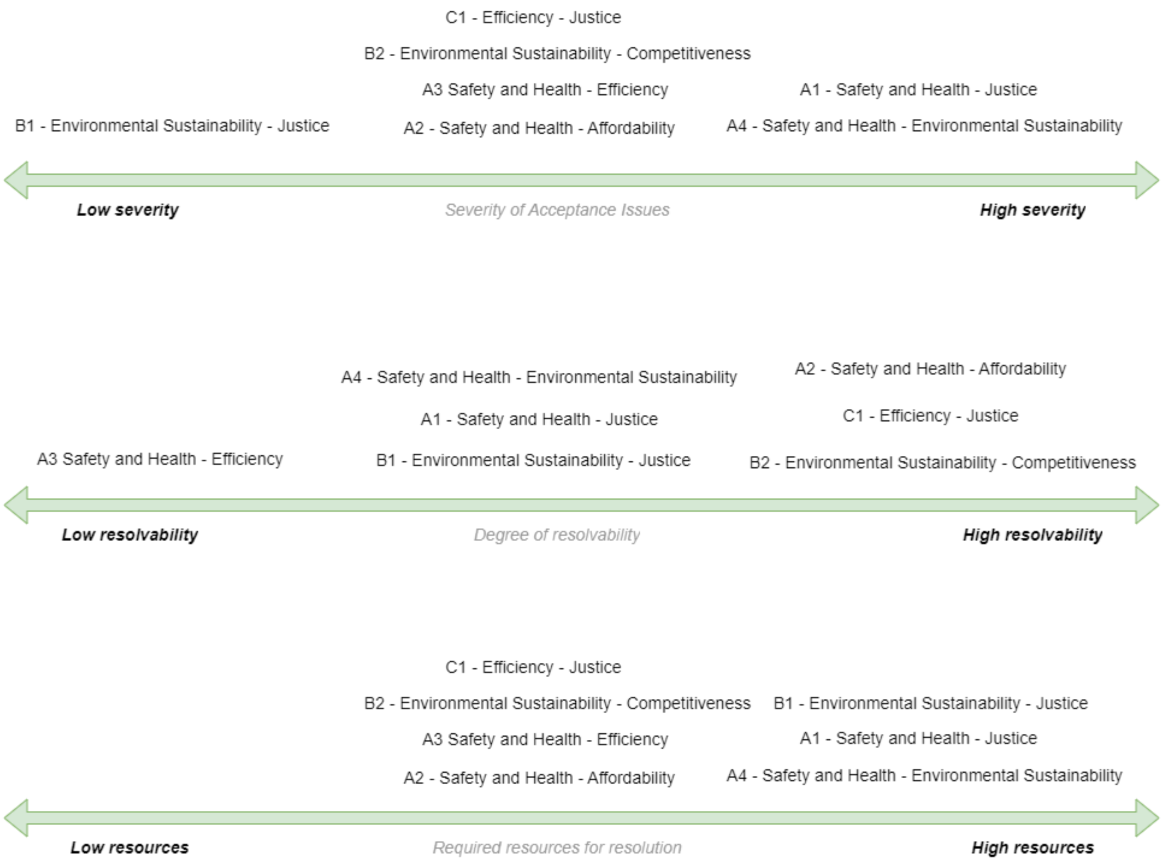

Figure 4.16: Value conflict classification based on resource requirements to solve value conflicts, social acceptance issues resulting from value conflicts and resolvability of value conflict.

5 Discussion

This chapter discusses the results of this study. This study had two research objectives: 1) The development and evaluation of an methodological framework to identify and address value conflicts in the adoption of hazardous chemicals in the energy transition and 2) identifying and addressing the value conflicts which play a role in the adoption of ammonia in the energy transition. Therefore, this discussion section will contain two main sections. The first section will evaluate the methodological framework by reflecting on the process of conducting the case study. The second section will contextualize the case study results by comparing the identified values and value conflicts which play a role in the adoption process of ammonia with values and value conflicts identified in related works.

5.1. Evaluating the methodological framework

The first objective of this research was to develop and evaluate a methodological framework for analyzing, addressing and classifying value conflicts in the adoption process of hazardous chemicals in the energy transition. Through literature review, it has been established that available approaches for value-driven design have mainly been developed for physical technological artifacts like wind-turbines or nuclear reactors (Oosterlaken, 2015; van de Poel et al., 2020). These approaches were found to not be suitable for analyzing the adoption process of hazardous chemicals within a socio-technical system like the energy system, because this system involves a much wider range of stakeholders and institutional implications.

By synthesizing the literature from the literature review and consultation with experts in the field of both systems engineering and ethics of technology, a novel methodological framework was developed to identify and address values and value conflicts which play a role in the adoption process of hazardous chemicals in the energy transition. The framework consisted of three steps, which are based on the three phases (conceptual-, empirical- and technical investigation) of tripartite value-driven design methods as described in Umbrello (2020). These three investigation phases are iterative and must be treated as a continuous feedback cycle.

To define the socio-technical system that the chemical of interested is adopted in, the Systems Thinking approach, which forms the foundation of the Systems Engineering approach, was utilized. By answering different questions about the objective of using the chemical within the system, the system boundaries and stakeholder interactions within the system, the framework provided a systematic and structured way of setting the context for the value-driven part of the framework. This framework step also included the conceptual value investigation, as the values of all identified stakeholders were conceptualized. Furthermore, by identifying the stakeholders which play a role in the adoption process of hazardous chemicals in the energy transition, participants for the expert interviews could be selected, which was needed to inform the second step of the framework.

Expert interviews and thematic analysis of the interview data were employed to identify values and value conflicts in the adoption process of an hazardous chemical in the energy transition as part of the empirical value investigation. For this empirical value investigation, also other approaches, like conducting a survey or performing document analysis could have been employed. It was chosen to work with expert interviews in this study because this approach allows to generate a large amount of relevant data in a relatively short time-frame. It was anticipated that it would be less convenient to use a survey, as it is a less flexible way of collecting data. During the semi-structured expert interviews, the interview structure and questions could be adapted depending on how knowledgeable the respondents of the study were on the topic of value-driven design and ethics of technology adoption. This would not have been the case when a survey would have been conducted. Compared to document analysis expert interviews provide an advantage because experts can identify emerging values and value conflicts that may not yet be documented, as they are at the forefront of their field.

By selecting a broad field of experts, validity of the results was ensured. However, a limitation of this case study is the fact that no local community members have been interviewed. To address this limitation, industry experts, policy advisors and research experts have been interviewed which did also have experience in the areas of public participation and citizen behaviour. These experts were asked on their opinion about how local communities should be involved in the adoption process.

Using a deductive coding process to initiate the thematic analysis provided structured analysis and efficiency of the interview data. A disadvantage of this method is however that it allows for limited flexibility to let new values emerge out of the data. Therefore, we also left room for the inductive emergence of values from the interview data. Still, no new values were identified inductively during the coding process.

The interview questions were based on related work, which also had the goal to identify values and value conflicts surrounding energy systems in the energy transition (Boijmans, 2019; Correljé et al., 2015; de Geest, 2016; Wildt, 2020). However, it was noticed that the interview questions were not suitable to derive specific technical design requirements for this context due to the broad nature of the socio-technical system which is affected by the adoption process of a chemical in the energy transition. With these interview questions (Appendix D), the conducted interviews focused more on the institutional design of the socio-technical system rather than the technological design of specific technological artifacts, like is the case in related VSD work. This is a limitation of the methodological framework as it was used now, as one of the objectives of the study was to also specify technical design requirements needed in the adoption process of an hazardous chemical in the energy transition. If future users of the framework want to derive specific technical design requirements for specific parts of the system, the interview questions should be adapted to zoom into certain system parts. If it is for example desired to obtain technical design requirements for ammonia storage facilities, then the interviewer should zoom in on this technological artifact explicitly in the interview (van de Poel, 2013).

Because general technical design requirements could not be derived for the process of ammonia adoption in the energy transition using the interview data, it was decided to only construct the value hierarchies up until the value-norm level. This value hierarchy provided useful for the value conflict identification, as comparing the norms related to the identified values provided a structured and systematic way to analyze how values could possibly conflict. This analysis relied partly on interpretation of the user of the framework, but to make the identification of the value conflicts more robust, also input from the expert interviews was used.

Published work on values and value conflicts has the tendency to not provide a practical way to prioritize and address value conflicts (Correljé et al., 2015; van de Poel, 2013). Therefore, we in this work aimed to provide the framework user with the tools to classify value conflicts and analyze the resources which can be used to address them. To address the value conflicts, we in this work use the approach of (technical and institutional) innovation (Correljé et al., 2015; van den Hoven et al., 2015). This approach tries to address value conflicts by suggesting technical and institutional design requirements, as well as stakeholder interactions which need to be created or enhanced to reduce or eliminate the value conflicts. Using expert interviews as input for this approach proved useful, as interviewees could easily reflect on institutional design requirements and stakeholder interactions they thought were missing in the adoption process of ammonia in the energy transition. The innovation method however is a non-optimizing method to deal with value conflicts in socio-technical design problems (van den Hoven et al., 2015). This means that no hard trade-offs need to be made between the values that are conflicting. Next to innovation, another non-optimizing method that could be used to address value conflicts in future work is satisficing (tresholds) (van den Hoven et al., 2015). When using satisficing, one does not look at the optimal design option, but sets a satisfactory treshhold and looks if the design options fulfills that treshhold. This could for example provide usefull when the value of Safety and Health is conflicting with other values, as a treshhold value for safety and health risks which is imposed on citizens could be enforced.

The limitation of using non-optimizing approaches like innovation and satisficing to address value conflicts is that these approaches do not always resolve the value conflict at play. If hard trade-offs needs to be made between two or more values in the socio-technical design because innovation or satisficing cannot address the conflict, multiple other approaches can be used (van den Hoven et al., 2015). The most pragmatic approaches are approaches where a quantitative comparison can be made between different design options, like MCDA or S-CBA (Choy, 2018; Höfer et al., 2019). Another approach to make hard value trade-offs is maximin, which works by selecting the design alternative that scores best, compared to the other alternatives, on its lowest-scoring value (van den Hoven et al., 2015). In future research, it should be explored if these approaches can also be integrated into the methodological framework.

The value conflict classification part of the framework was included to provide a way to prioritize value conflicts, which can be useful from a policy perspective. However, as the main objective of the conducted interviews was to identify values and value conflicts which play a role in the adoption process of hazardous chemicals in the energy transition and gather information about (technical and institutional) innovation and stakeholder interactions which can be put in place to address the value conflicts, the interviews did not provide input for the value classification. Therefore, the parts of the framework where social acceptance issues which can results from value conflicts and the resolvability of value conflicts is discussed became rather speculative based on the framework users opinion. This part thus mainly should be seen as a methodological demonstration of how value conflicts can be classified. Future framework alterations should make use of focus groups or participatory workshops with stakeholders or experts to enhance the scientific validity of the value conflict classification. This participatory approach can also improve the framework by incorporating more diverse stakeholders perspectives and ensuring that the proposed solutions are practically viable and socially acceptable.

5.2. Contextualizing the case study results

5.2.1. Value identification

The second objectives of this study was to use the developed methodological framework to identify the values and value conflicts which play a role in the adoption process of ammonia in the Dutch energy transition and analyze how these values conflicts can be addressed. Analyzing the stakeholder landscape revealed that the adoption process was mainly influenced by three stakeholder groups being the (local and national) government, industry and local communities. The government sets the regulatory boundaries for the production, transport and use of ammonia in the Dutch energy transition, and develops a vision on the role that ammonia should play in the energy transition, balancing the advantages and disadvantages of the chemical. The industry tries to substitute the fossil fuel demand with greener alternatives, where green ammonia could play a role by substituting grey ammonia, serving as fuel for the marine industry of coal-fired power plants or serving as a liquid hydrogen carrier. As they are no public institution, industry players always have an economically driven perspective, which also has implications on their values. Local communities are the stakeholders which have to accept the predicted increase in ammonia production, transport and use near their living environment. The government needs support for their energy transition plans by local communities to prevent public opposition to the energy transition.

The values which play a role in the adoption process of ammonia in the Dutch energy transition were then empirically investigated by conducting expert interviews. Thematic analysis of the qualitative interview data revealed seven major values in the adoption process being efficiency (of both spatial planning and the energy transition in general), competitiveness, cooperation, safety and health, environmental sustainability, transparency and (procedural and distributive) justice. Minor values that were identified from the thematic analysis were affordability, reliability, security of supply and accountability, but played a lesser role in the adoption process. These values were all present in the deductive list of values that initiated the coding process. Values which were not identified from the interview data, but were present in the deductive code list were international stability, trust and aesthetics. Not identifying some of these values based on the interview data can be debated, because for example the values of security of supply and international stability are somewhat connected. The same holds for the identified values (procedural) justice and transparancy, and the non-identified value trust.

Upon reflecting on the values identified from the thematic analysis, it was noted that the value of security (protection against the intentional misuse of a technology) was missing. This was unexpected, given that storing and transporting large quantities of a hazardous chemical like ammonia could potentially be a target for attacks. To understand why this value is absent, an expert in national security from the RIVM was consulted. The expert indicated that this is currently a blind spot: security risks associated with the storage or transportation of hazardous substances are rarely considered in policy-making. For example, the pipeline infrastructure of the national gas network operator still views accidental damage from digging as the greatest threat, without accounting for the possibility of deliberate attacks (Gasunie, n.d.). The blind spot of considering security in policy making regarding the storage and transport of hazardous chemicals could be partly attributed to a lack of incidents where the storage or transport modalities of hazardous substances have been intentionally targeted in attacks. In contrast, such considerations are made for nuclear power plants. Should ammonia storage facilities not be viewed with the same level of security concern as nuclear reactors, which have reinforced roofs to protect against potential plane crashes or attacks?

While a terrorist attack on hazardous substance storage or transport seems unlikely, as other methods could create more chaos and casualties with less efforts, the threat could come from state actors with the capabilities to execute such actions. Given the current geopolitical tensions in the world, the Netherlands could be a target for Russia due to the logistics lines (military materials, personnel) from the United States to Ukraine passing through the Port of Rotterdam (Osinga, 2024). If large storage and transport facilities for potentially hazardous will be built in the port of Rotterdam, like is the plan for ammonia, these could be a target for deliberate attacks. This indicates that there is a need to transition from 'safe by design' thinking to 'safe and secure by design' thinking in the energy transition. This approach would ensure not only the safety but also the security of hazardous chemical storage and transportation against potential threats.

5.2.2. Values identified in related works

The deductive code list used for the thematic analysis was composed based on the work of Dignum et al. (2015), Milchram, Hillerbrand, et al. (2018), and Wildt (2020) who respectively investigated values and value conflicts concerning shale gas field exploitation and the adoption of the smart energy grid. Based on the fact that almost all deductive values were identified, it can thus be concluded that the values which play a role in the adoption of hazardous chemical in the energy transition are comparable with the values which play a role in these cases. The conception of the values identified in related works can however be different compared to the conception of the values identified in this work, which necessitates a further analysis of the values at play.

As also observed in Dignum et al. (2015), the identified values could be split in *substantive values* and *procedural values*. Substantive values relate to the technology of ammonia production, transport and use and the effects of projects concerning ammonia (e.g. the construction of a new production plant or pipeline). Major substantive values identified were competitiveness, safety and health, environmental sustainability and efficiency (of sptial planning). Minor substantive values identified were affordability, reliability and security of supply. Procedural values relate to the nature of the rules and regulations and the procedures that constitute the decision-making on adoption of ammonia. Major procedural values that were identified are efficiency (of the energy transition), cooperation and (procedural and distributive) justice. A minor procedural value that was identified was accountability.

It was hypothesized that the values which play a role in the adoption of nuclear energy would be similar to the adoption of hazardous chemicals in the energy transition, as both cases involve major safety and health concerns. Van de Poel et al. (2020) identified six values which play a role in the adoption of nuclear energy in the energy transition, being economic viability, safety, security, resource durability, environmental benevolence and intragenerational justice. This list of values also shows similarities with the values identified in this work. Economic viability is in our study defined as competetiveness, while our definition of environmental sustainability shows similarities with their definition of environmental benevolence. Intragenerational justice was not mentioned to play a role in the adoption of ammonia in the Dutch energy transition. However, this value also comes back in the conception of the value of reliability (technological lock-in) in this study. The fear that we will be dependent on ammonia production, transport and use in the Dutch energy system, while there are alternatives available with less safety and health concerns, also has an intragenerational justice component.

Hall et al. (2013) identified four value themes which are important in the social acceptance process during the adoption of wind turbines and wind parks being trust, distributive justice, procedural justice, and place attachment, of which the last one is connected to the aesthetics of the wind turbines. Oosterlaken (2015) complemented this analysis by identifying ecology, cost-effectiveness and economic feasibility as values which play a role in the adoption process of wind turbines and wind parks. The procedural values identified in this work are similar to the values which were identified in their works. The substantive values identified also show overlap, but the identification of substantive values in this study is more extensive. Aesthetics is again mentioned as a value in the adoption process in these studies, but was not found to play a role in the adoption process of hazardous of chemicals in the energy transition. This is probably due to the fact that ammonia production, transport and use are not as visible as e.g. nuclear reactors or wind turbines for local communities. For most stakeholders, a chemical plant is just a chemical plant, and the connection with ammonia when thinking about a chemical plant is not automatically established.

5.2.3. Value sentiments

It was noticed that the same value could have a positive and negative sentiment, depending on the interview. This was for example the case with the value of safety and health. Here it was noticed that stakeholders with technical expertise, like a researcher specialized in pipeline transport and a consultant with expertise in the construction of ammonia terminals were positive about the risks connected to the use and transport of ammonia in the energy transition. People with less technical expertise, like policy advisors, showed a more negative and precautious sentiment around the safety and health risks connected to using ammonia in the Dutch energy transition. The observed variation in value sentiments shows the need for including a diverse range of experts into the expert interview process, so that diverse value perspectives can be considered.

5.2.4. Value conflict identification

Seven value conflicts were identified by comparing the norms related to the values being Safety and Health versus Justice, Affordability, Efficiency, and Environmental Sustainability; Environmental Sustainability versus Justice and Competitiveness; and Efficiency versus Justice. Because of time constraints, it is not feasible to discuss all of these value conflicts in depth. Therefore, we zoom into three value conflicts being: 1) the value conflict between Safety and Health and Justice, 2) the value conflict between Environmental Sustainability and Competitiveness and 3) the value conflict of Efficiency versus Justice.

The value conflict between Safety and Health and (distributive) Justice in the energy transition already has received significant attention in the academic debate. This value conflict boils down to how risks can be minimized so that the well-being of individuals affected by hazardous chemicals can be guaranteed, while also providing room for energy transition initiatives. The government here has to ensure that no specific stakeholder groups disproportionately bear the risks or gets the rewards. Several studies highlight this tension. For example, Correljé et al. (2015) discuss how unequal risk distribution can occur in the energy transition, especially if industrial activities are located near disadvantaged neighborhoods. Similarly, Milchram, van de Kaa, et al. (2018) note that marginalized communities often face higher exposure to environmental risks without commensurate benefits. They highlight the importance of equitable policy frameworks that address this value conflict.

In the context of ammonia adoption in the energy transition, this value conflict is mostly recognized in the spatial distribution of risks and benefits. Local communities near ammonia production, transport, and storage sites may bear increased health and safety risks compared to other communities. The literature often calls for inclusive decision-making processes in this case to ensure that all stakeholders' voices are heard and their concerns addressed (Hall et al., 2013; Noordegraaf - Eelens et al., 2012; van de Poel et al., 2020). This would simultaneously also address the value conflict between Efficiency and (procedural) Justice.

Because green chemicals are often not yet price-competitive with chemicals produced via grey production methods, the values of Environmental Sustainability and Competitiveness can conflict in the adoption process. This calls for financial incentives to make green ammonia competitive with grey ammonia. For imported green ammonia, standards can be enforced to allow verification that the ammonia is actually produced green (ECHA, 2020).

6 Conclusion

Concluding, this study successfully developed and evaluated a methodological framework for analyzing and addressing value conflicts in the adoption of hazardous chemicals in the energy transition by integrating principles from the systems engineering approach and value-driven design methods. As no methodological framework for this context existed yet, this study provides a valuable contribution to the field of value sensitive design of socio-technical systems. After framework evaluation by reflecting on the process and results of conducting a case study on ammonia adoption, multiple framework revisions are proposed for future framework generations. While the conducted expert interviews provided valuable insights into values and value conflicts, the broad scope limited the derivation of specific technical design requirements, indicating a need for more focused interview questions in future research. The framework still effectively constructed value hierarchies up to the value-norm level, which provided useful for the identification of value conflicts. Addressing these conflicts through institutional innovation and enhancing or creating stakeholder interactions proved effective. To increase the framework usability future framework iterations should also explore additional methods to address value conflicts. Further frameworks improvements include refining the interview questions to derive technical design requirements and making the value conflict classification more scientifically robust through expert focus groups.

Next to developing and evaluating the methodological framework, this study identified the values and value conflicts which play a role in the adoption process of ammonia in the Dutch energy transition. Thematic analysis of 11 expert interviews identified seven major values being efficiency, competitiveness, cooperation, safety and health, environmental sustainability, transparency, and (procedural and distributive) justice. Minor values included affordability, reliability, security of supply, and accountability. These values were comparable to those found in related works on shale gas exploitation and smart energy grids, indicating a common set of concerns across different energy contexts. Substantive values related to the technology and effects of ammonia projects, while procedural values related to transparent decision-making processes. The value of security was not identified in the value identification, which indicates that this is a blind spot in the adoption of hazardous chemicals in the energy transition. Value conflicts were particularly observed between Safety and Health versus Justice, and Environmental Sustainability versus Competitiveness. It was suggested that these value conflicts should be addressed through transparent and inclusive governmental communication and decision-making, a clear governmental vision on the ethical dilemmas that need to be faced in the energy transition, strong government-industry collaboration and green ammonia certification standards.

7 Policy Implications

Based on the findings in the technical investigation phase of the case study, several policy implications can be suggested to address the identified value conflicts and enhance the adoption process of ammonia in the energy transition:

- There is a need for more transparent communication with the public about the energy transition, available technology alternatives to reach net-zero, associated risks of those alternatives, and the ethical dilemmas that the government is facing. Local communities are willing to bear risk, if the government clearly states what the ethical dilemmas are which need to be faces in the energy transition and which choice are made in these ethical dilemmas (Noordegraaf - Eelens et al., 2012). This vision can build social community acceptance from the industry and local communities and address the value conflicts between safety and health, justice, and efficiency.
- The government should articulate a clear vision on the ethical desirability of adopting certain chemicals in the energy transition. For this vision it is necessary that the government has specified the intended use-cases for e.g. green ammonia, whether it is intended for substituting grey ammonia, as an energy carrier, or as a hydrogen carrier. This clarity can help address value conflicts related to competitiveness and environmental sustainability.
- It is important that the government keeps fostering a strong collaboration between industry and government. This is especially important considering chemicals which are new or where only little expertise is present on at the government, as the industry might be in possession of the needed technical knowledge. Based on this knowledge, the government can then set regulatory and policy directions, enhancing regulatory preparedness. Industry-Government collaboration can in this way help resolve value conflicts related to safety and health, competitiveness and environmental sustainability.
- To make sure that the imported ammonia is produced green, certification standards should be put in place. Additionally, international agreements and collaborations with exporting countries can help in this process. For locally produced ammonia, subsidies could be given to support the production of green ammonia and make it competitive with grey or blue ammonia while needed. This could address the value conflict between environmental sustainability and competitiveness.
- To enhance national security, governments should integrate 'safe and secure by design' principles in the policy-making concerning the storage and transport of hazardous substances like ammonia. This includes strengthening infrastructure against potential attacks, similar to the security measures taken for nuclear reactors, and conducting risk assessments that consider both accidental and deliberate threats. Collaboration with industrial and academic security experts to address this policy blind spot is essential to mitigate risks in the current context of increasing geopolitical tensions.

8 Academic Recommendations

From the Discussion chapter, recommendations about further academic research opportunities can be given.

- The revised version of the methodological framework as suggested in the Discussion section should be evaluated and refined further by re-applying it to study the adoption process of ammonia in the Dutch energy transition. Conducting focus groups as part of the methodological framework in the next round will allow to draw more robust and scientifically sound conclusions about how to address value conflicts. Furthermore, in future framework generations, other methods to address value conflicts next to innovation, like satisficing, MCDA, S-CBA or maximin should should be integrated to expand its usability.
- In the future application of the developed framework, the values of local community members which are affected by the adoption process of a hazardous chemical should be taken into account directly. In this work, the values of local communities were accounted for by letting other stakeholders (policy advisors, industry experts) reflect on the effects of the adoption of a chemical in the energy transition on local communities. This is however an indirect way of accounting for their values. Involving local community members as part of data collection would be more scientifically robust.
- To ensure the generalizability of the framework, it should be tested how it performs when the adoption process of other hazardous chemicals in the energy transition is studied. This can help to refine the framework, because other methodological points of improvement which did not emerge when studying the adoption process of ammonia could emerge across different contexts.
- The developed methodological framework provides a useful tool to identify and address value conflicts in the adoption process of hazardous chemicals in the energy transition. However, values and value conflicts are not static, they can change over time (de Wildt et al., 2018; van de Poel & Taebi, 2022). It would thus be interesting to use the methodological framework at multiple points in time for a specific chemical to monitor changes in values and value conflicts. Apart from providing information about the effectiveness of the institutional design requirements and stakeholder interactions put in place, the findings can also contribute to the scientific field of studying value change.

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A

Literature Review Methodology

The literature review to base the methodological framework on was conducted using a systematic and comprehensive approach. The search aimed to identify relevant studies, articles and reports that address the key aspects of the research topic. To answer the literature study sub-questions as put forward in the introduction (Subsection 1.2.2), the literature review existed out of three parts: 1) Using the Systems Engineering approach to analyze a socio-technical system, 2) The importance of values for technology acceptance in socio-technical systems and 3) Considering values in the design of socio-technical systems. For each of these parts, a high-impact article which was deemed of high importance to that specific research field was selected and a backward- and forward reference search was conducted. For the Systems Engineering part, the work of Polojärvi et al. (2023) was selected, for the importance of values in social acceptance of technologies, the work of Künneke et al. (2015) was selected and for the part about value-driven design of socio-technical systems, the book chapter of Correljé et al. (2015) was selected.

To complement the backward- and forward reference search, also a systematic literature search was conducted using Scopus. This database was used as the main literature search platform because of the interface completeness. It has ample options to adjust different parameters to collect the most relevant scientific articles. Table A.1 shows the keywords and synonyms used in (different combinations in) Scopus.

Table A.1: Keywords and synonyms used in Scopus

Systems Engineering	Social Acceptance of Technology	Value-Driven Methods
Systems Engineering	Social Acceptance	Value Sensitive Design
Socio-technical Systems Design	Technology Acceptance	Design for Values
Systems Design	Public Acceptance	Ethical Design
Systems Thinking	Community Acceptance	Participatory Design
	Technology Adoption	

The abstracts of the found articles were scanned for their relevance to this study. It was expected that the literature resulting from this search would not all be relevant for answering the research questions of this work. Hence, the search selection criteria as shown in Table A.2 were used. Articles needed to be peer reviewed and published in journals. As the foundation of the Systems Engineering approach was laid during the Second World War and scientific research on value-driven design methods and social acceptance of technologies emerged much later, only publications from 1950 onwards were selected. Language needed to be written in English or Dutch, and the research should be related to the research topic. The geographic focus of the articles can be anywhere. The application of these search description and selection criteria ensured the inclusion of high quality, relevant literature that contributes to answering the research questions. As the body of literature on the systems engineering approach and social acceptance of technology was found to be very large, even when using the inclusion and exclusion criteria, articles were scanned until a sufficient answer on the sub-questions as put forward in subsection 1.2.2 could be given.

Table A.2: Inclusion- and Exclusion criteria

Criteria	**Inclusion**	**Exclusion**
Publication Type	Peer-reviewed journal articles	Conference abstracts, dissertations, editorials
Publication Date	After 1950	Earlier than 1950
Language	English and Dutch publications	Non-English and Non-Dutch publications
Research Focus	Studies related to the research topic	Studies unrelated to the research topic
Geographic Focus	Worldwide	None

B

List of attended expert meetings and unstructured interviews

Table B.1: Attended expert meetings and unstructured interviews for stakeholder identification

Date	What	Organization	Topic
2/20/2024	Meeting	RIVM Internal	Brainstorm meeting for stakeholder identification with RIVM experts
2/29/2024	Meeting	RIVM Internal	Exchange research and points of view regarding ammonia
3/5/2024	Meeting	RIVM Internal	Brainstorm meeting for stakeholder identification with RIVM experts
3/7/2024	Knowledge exchange day	Ministry of Economic Affairs and Climate	Day organized by the project directors of the Delta Rhine Corridor to exchange knowledge, views and expertise regarding the transport of ammonia in the Netherlands
3/12/2024	Meeting	RIVM Internal	Exchange research and points of view regarding ammonia
3/27/2024	Conference	Association of Environmental Professionals	Conference about external safety in the energy transition
4/2/2024	Meeting	RIVM Internal	Exchange research and points of view regarding ammonia
Various dates	Meeting	RIVM Internal	Supervisor progress meetings to brainstorm about the production, transport and use of ammonia in the energy transition

C

HREC Approval

Date 19-Mar-2024
Contact person Grace van Arkel, Policy Advisor
Academic Integrity
E-mail E.G.vanArkel@tudelft.nl

TU Delft Delft University of Technology

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The Netherlands

Ethics Approval Application: Value-Driven Evaluation of Liquid Hydrogen Carriers for Transport of Hydrogen
Applicant: Houdijk, Sam

Dear Sam Houdijk,

It is a pleasure to inform you that your application mentioned above has been approved.

Thanks very much for your submission to the HREC which has been conditionally approved. Please note that this approval is subject to your ensuring that the following condition/s is/are fulfilled:

The applicant expresses an intention not to share any data with the partner organisation. It would be advisable to make this more concrete as a commitment, or to specify under what conditions data would be shared, in order to remove ambiguity and reinforce the possibilty for informed consent.
Same point for DMP answer 24. DMP answer 10 should include mp4 audio files too.

In addition to any specific conditions or notes, the HREC provides the following standard advice to all applicants:
• In light of recent tax changes, we advise that you confirm any proposed remuneration of research subjects with your faculty contract manager before going ahead.
• Please make sure when you carry out your research that you confirm contemporary covid protocols with your faculty HSE advisor, and that ongoing covid risks and precautions are flagged in the informed consent - with particular attention to this where there are physically vulnerable (eg: elderly or with underlying conditions) participants involved.
• Our default advice is not to publish transcripts or transcript summaries, but to retain these privately for specific purposes/checking; and if they are to be made public then only if fully anonymised and the transcript/summary itself approved by participants for specific purpose.
• Where there are collaborating (including funding) partners, appropriate formal agreements including clarity on responsibilities, including data ownership, responsibilities and access, should be in place and that relevant aspects of such agreements (such as access to raw or other data) are clear in the Informed Consent.

Good luck with your research!

Figure C.1: Human Research Ethics Committee TU Delft Letter of Approval

D

Interview Protocol

Introduction
Duration: 10 minutes

- Introduction of the interviewer and the interviewee.
- Explanation of research goal.
- Explanation of interview objectives.
- Discussion of Human Research Ethics form and signing the Informed Consent form.

Context and stakeholders
Duration: 5 minutes

- What is your link to ammonia in the energy transition?
- What other parties are you working with concerning the adoption of ammonia in the energy transition?

Ethical dilemmas in the adoption of ammonia in the energy transition
Duration: 20 minutes

- What ethical dilemmas do you see in the adoption of ammonia in the energy transition?
- From which stakeholders do these dilemmas arise?
- What aspects should be prioritized when adopting ammonia in the energy transition from your perspective?
- What do you expect to be the biggest obstacles in the large-scale adoption of ammonia in the energy transition?
- How can these obstacles be resolved from both technical and institutional perspectives?

Stakeholder interactions in the adoption of ammonia in the energy transition
Duration: 20 minutes

- Do the processes in which the different groups of stakeholders interact allow for taking into account the needs, wishes and concerns of all stakeholders?
- How are the concerns of local communities taken into account?
- Do you think there is consensus between different stakeholders about the prioritization of different values (e.g. the importance of safety, sustainability and economic growth)?

Wrap up
Duration: 5 minutes

- Reflection on any topics or issues not discussed that relate to the ethical dilemmas/value conflicts in the adoption of ammonia in the energy transition.

E

Coding principles

By drafting a list of coding principles, the researcher clarifies the process of how the coding process is conducted and how certain codes are interpreted. By making these principles explicit, the validity of the results is increased. The principles as stated here are partly adapted from Milchram, Hillerbrand, et al. (2018).

- A deductive code book with potentially relevant values for the adoption of hazardous chemicals within the energy transition, their definition and semantic fields is composed based on literature review on ethics of technology.
- The code book can be changed during the coding process, according to the *sensitizing concepts* principle. This means that while coding, new codes can be added, code definitions can change and codes can be merged and splitted.
- Statements that are attributed to a certain value are also classified based on the expressed sentiment. This can be positive (in favor of ammonia being adopted in the energy transition), neutral, or negative (against ammonia being adopted in the energy transition).
- If a value-laden statement is presented, the source of the statement will be named.
- statements have to be explicitly in the context of the adoption of ammonia in the energy transition. Statements which contain values but refer to general energy systems design, hydrogen transport in general or else are excluded.
- An inter-coder agreement check is performed with a fellow Master-student to enhance the validity of the results. Provided with this list of coding principles and a description of the research goal and coding context, the other person follows the same coding protocol. If there are differences in the way that this person codes compared to the researcher in this study, a discussion will be held to solve the discrepancies.

F

Value Definitions and Semantic fields

Table F.1: Deductive list of values and definitions from various sources. As only the values which were taken from Wildt et al. (2019) were defined, the values taken from the other studies were defined by the author of this research.

Source	Value	Definition
Dignum et al. (2015)	International stability	Condition of global peace and security where nations are able to coexist without significant conflicts that can lead to war or disruptions
Dignum et al. (2015)	Affordability	The accessibility of goods, services, or resources in terms of their cost being within the economic reach of individuals or communities.
Dignum et al. (2015)	Transparency	Making information available and understandable to stakeholders
Milchram et al. (2018)	Aesthetics	The appreciation of beauty or good taste, within various contexts such as art, design, and environments.
Milchram et al. (2018)	Accountability	The obligation to report, explain, and be answerable for the consequences of actions taken.
Milchram et al. (2018)	Distributive justice	The equitable division of resources and burdens, ensuring fairness and impartiality.
Milchram et al. (2018)	Procedural justice	Ensuring that the systems in place are just, impartial, and fair.
Milchram et al. (2018)	Security of supply	The availability of essential goods and utilities in sufficient quantities at all times.
Milchram et al. (2018)	Cooperation	Working together towards common goals or interests
Milchram et al. (2018)	Trust	The belief in the reliability, truth, ability, or strength of someone or something
Wildt et al. (2019)	Environmental sustainability	Ensuring that the system does not overburden ecosystems, allowing current and future generations to meet their needs.
Wildt et al. (2019)	Safety and health	Ensuring that the system does not cause harm to people.
Wildt et al. (2019)	Efficiency	High operational effectiveness of the system, as measured by comparing production and costs (including energy, time, and money).
Wildt et al. (2019)	Reliability	The ability of the system to perform consistently under a range of conditions without failure.
Wildt et al. (2019)	Competitiveness	Providing an economic advantage in the marketplace.

Table F.2: Semantic Fields of pre-composed list of values in Dutch

Value (EN)	Value (NL)	Semantic Field (NL)
International stability	Internationale stabiliteit	diplomatie, onderhandelingen, verdragen, allianties, handelsovereenkomsten, klimaatakkoord, wereldmarkten, economische samenwerkingsverbanden
Affordability	Betaalbaarheid	kostenbeheersing, kostenefficient, financiële toegankelijkheid, prijs-kwaliteit verhouding
Transparency	Transparantie	klaarheid, helderheid, toetsbaar, controleerbaar
Aesthetics	Esthetiek	visuele aantrekkelijkheid, beeld, natuurlijk ontwerp, harmonie met omgeving
Accountability	Verantwoordelijkheid	aansprakelijkheid, plicht, taak, verplichting, bevoegdheid
Distributive justice	Verdelende rechtvaardigheid	oneerlijkheid, onrecht, rechtvaardig, onpartijdig, oneerlijk, onbevooroordeeld, rechtvaardigheid, objectiviteit, gelijkheid, wettelijk, egalitair, distributief
Procedural justice	Procedurele rechtvaardigheid	oneerlijkheid, onrecht, rechtvaardig, onpartijdig, oneerlijk, onbevooroordeeld, rechtvaardigheid, objectiviteit, gelijkheid, wettelijk, egalitair, distributief
Security of supply	Leveringszekerheid	energiezekerheid, robuustheid, afhankelijkheid van andere landen
Cooperation	Samenwerking	samenwerkingsverband, samen, medewerking, coöperatie, collaboratie, synergie
Trust	Vertrouwen	geloof, bouwen op, steunen op, hoop, toevertrouwen, betrouwbaar, betrouwen, ervan uitgaan
Environmental sustainability	Milieuduurzaamheid	duurzaamheid, duurzaam, natuurlijk, ecologisch, milieuvriendelijk, natuurvriendelijk, intergenerationeel, hernieuwbaar, milieu, klimaat, duurzaamheid, gelijkheid, eerlijk
Safety and health	Veiligheid en gezondheid	gevaar, nood, bedreiging, gevaarzetting, risico, gezondheid, ziekte, ongezondheid, vreselijk, welzijn, veilig, schadelijk, gezondheid, onhoudbaar
Efficiency	Efficiëntie	effectiviteit, werkzaamheid, ineffectiviteit, inefficiëntie, productiviteit, prestatie, fit
Reliability	Betrouwbaarheid	veerkracht, sterkte, onbreekbaar, aanpasbaarheid, integriteit, breekbaar, instorten, falen, betrouwbaarheid, onderhoudbaarheid, veiligheid
Competitiveness	Concurrentievermogen	kandidaat, rivaal, niet-concurrent, marktstructuur, toetredingsbarrières, monopolie, oligopolie, concurrentie, betwistbaarheid, strategisch gedrag, concurrentie, complementaire activa, concurrerend, voordeel, belanghebbenden

G
Thematic Analysis

The table on the next page summarizes the identified values, sentiments, conceptions and interview source attributions from the thematic analysis of the interview data.

Table G.1: Value identification from thematic analysis

Value	Sentiment	Conception	Interview Source
Environmental Sustainability	Negative	Nitrogen crisis	Energy Transition Consultant
	Negative	Greenwashing	Policy Advisor
	Negative	Green ammonia TRL	Policy Advisor
Safety and Health	Positive	External safety of pipelines	Researcher Industrial and Environmental Safety
	Positive	External safety of rail transport	Policy Advisor
	Negative	Toxic properties in case of leakage	Safety Consultant
	Negative	Experience of personnel	Port Manager
	Negative	No action perspective when accident happens	Policy Advisor
	Positive	Safety of storage	Consultant Ammonia Terminals
Efficiency	Negative	For use as hydrogen carrier	Policy Advisor
	Positive	For direct use as fuel/fertilizer	Consultant Ammonia Terminals
	Negative	Spatial planning	Port Manager
Justice	Positive	Procedural Justice	Port Manager
	Positive	Procedural Justice	Policy Advisor
	Negative	Distributive Justice	Policy Advisor
			Researcher Industrial and Environmental Safety
Competitiveness	Positive	Choice for ammonia	Port Manager
	Neutral	Substituting existing industry	Policy Advisor
Affordability	Negative	Price	Market player
	Negative	Subsidizing ammonia	Policy Advisor
Cooperation	Neutral	Market-Government Interplay	Researcher Industrial and Environmental Safety
	Negative	Knowledge sharing	Researcher Industrial and Environmental Safety
	Neutral	International Collaboration	Researcher Industrial and Environmental Safety
Transparency	Positive	Participation process	Researcher Industrial and Environmental Safety
	Positive	Transparancy about ethical dilemmas	Energy Transition Consultant
Accountability	Positive	Taking responsibility	Consultant Ammonia Terminals
Security of Supply	Neutral	Dependency on Russian gas	Safety Consultant
Reliability	Negative	Technological lock-in	Port Manager
			Policy Advisor

H

Stakeholder Identification

Below, the conceptual stakeholder (value) identification can be found, which elaborates on Figure H.1 by specifiying the stakeholders role, interests and values. Due to the length of this table, it was not possible to provide a well aligned latex table in this appendix. Therefore, below a pdf is inserted. This does not allow a table caption, so therefore it is not present in the table below.

Group	Stakeholder	Role	Interests	Values
European Union	European Commission	Policy formulation, regulation, coordination	Sustainable economic development, climate policies	Wellbeing, Sustainability, Equality, Safety
	OECD	Economic policy knowledge development	Research advancements, evidence-based policies	Innovation, Safety, Economic Stability
	JRC (Joint Research Centre)	Scientific and technical knowledge development	Research advancements, evidence-based policies	Innovation, Safety, Economic Stability
National Government	Ministry of Justice and Safety	Ensuring national justice and safety	Responsible for the fire department	Safety, Equality
	Ministry of Social Affairs and Employment	Ensuring equal, healthy and safe working conditons	Responsible for occupational safety	Wellbeing, safety, equality
	Ministry of Economic Affairs and Climate Policy	Formulating economic and climate policies	Sustainable economic growth	Wellbeing, Sustainability, Equality, Safety, Economic growth
	Ministry of Infrastructure and Water Management	Infrastructure planning and management	Sustainable and safe infrastructure, water management	Wellbeing, Sustainability, Equality, Safety
	The Human Environment and Transport Inspectorate	Safety, confidence and sustainability in regard to transport, infrastructure, environment and housing.	Regulator of Ministry of Infrastructure and Water Management	Wellbeing, Sustainability, Equality, Safety
	Authority for Consumers and Markets	Ensuring fair competition and protecting consumers	Consumer protection, market efficiency	Fair Competition, Consumer Rights

	State Control of the Mines	Regulating and overseeing (gas)mining activities	Resource extraction, environmental protection	Environmental Responsibility, Safety
	Labour Authority	Labour market regulations and worker rights	Fair labour practices, workplace safety	Workers' Rights, Safety
	Telecom Agency	Keeps track of networks overground and underground to prevent excavation damage (graafschade)	Efficient, reliable and accessible telecom services	Connectivity, Accessibility, Safety
	Universities	Academic research	Develop knowledge	Connecting, innovation, responsibility, freedom
	RIVM (National Institute for Public Health)	Public and environmental health and policy research	Public health, disease prevention, environmental safety	Public and environmental health, Safety
	NIPV (National Institute for Public Values)	Public knowledge institute for crisis management and fire services.	Public health, disease prevention, environmental safety	Public and environmental health, Safety
Regional Government	Provinces	Regional governance and planning, permits	Regional development, resource management, safety	Regional Development, Sustainability, Safety, Equality
	Municipalities	Local governance and services, permits	Regional development, resource management, safety	Regional Development, Sustainability, Safety, Equality
	Environment Agencies	Environmental protection and monitoring, permits	Biodiversity, pollution control, safety	Environmental Conservation, Sustainability, Safety

	Safety Regions	Emergency response and disaster management	Public safety, disaster preparedness	Safety
	Fire Departments	Fire prevention and emergency response	Fire safety, community protection	Safety
Hydrogen End Users	Chemical Industry	Hydrogen utilization in chemical processes	Cost-effective and sustainable processes	Sustainability, Profitability, Safety
	Shipping Industry	Hydrogen as a fuel for maritime transport	Clean and efficient shipping	Sustainability, Profitability, Safety
	Energy Industry	Hydrogen as an energy carrier and storage	Renewable energy, energy security	Sustainability, Profitability, Safety
Transportation Sector	Ports	Hydrogen-based transport and logistics	Sustainable port operations, emissions reduction	Sustainability, Profitability, Safety
	Shipping Companies	Integration of hydrogen in shipping operations	Cost-effective and sustainable shipping	Sustainability, Profitability, Safety
Infrastructure Sector	Infrastructure Companies	Development and maintenance of hydrogen infrastructure	Reliable and efficient infrastructure	Reliability, Efficiency, Safety
Local Communities	Citizens	Use of energy system	Community well-being, local development	Well-being, Equality, Safety

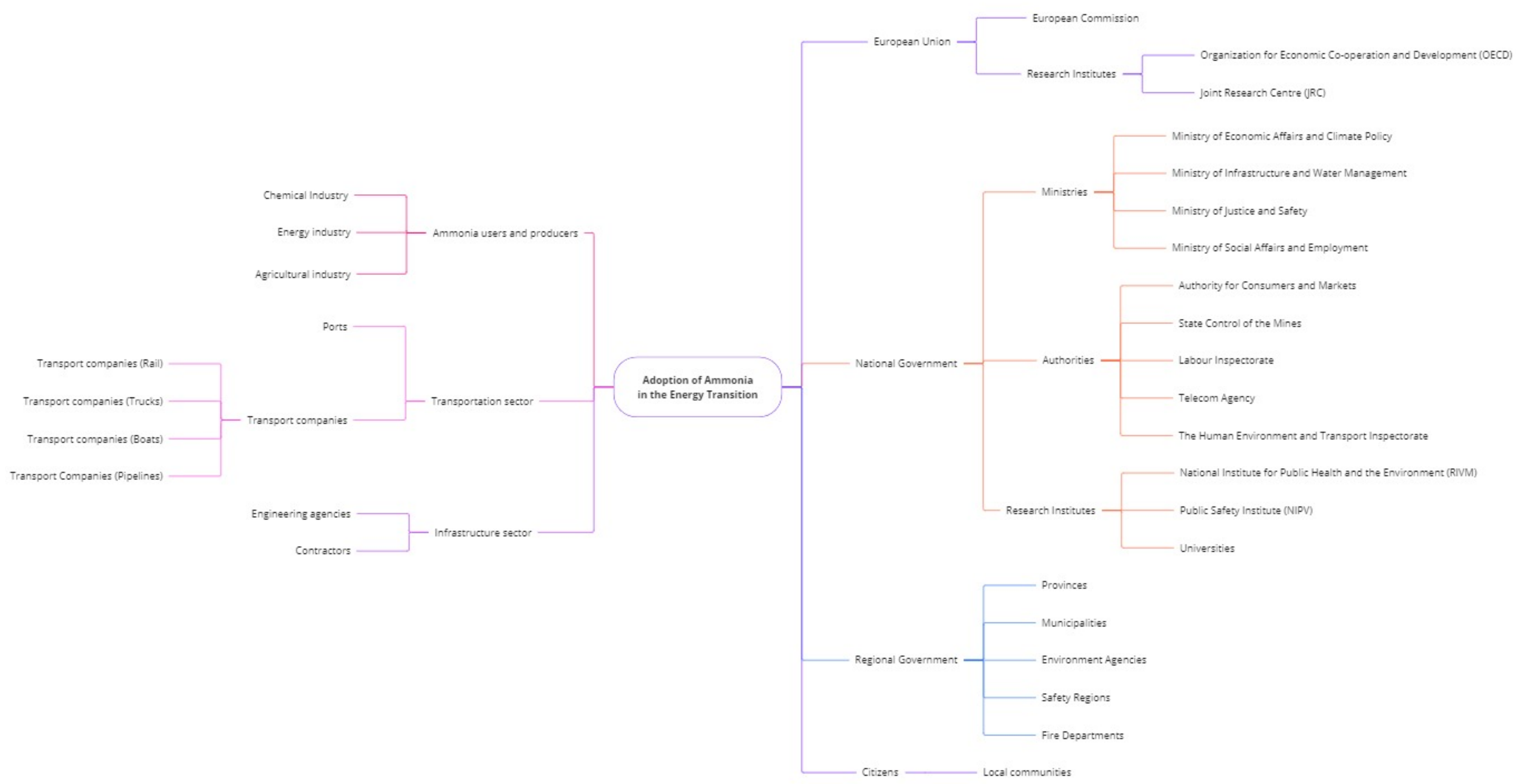

Figure H.1: Stakeholders identified concerning the adoption of liquid hydrogen carrier molecules in the Netherlands. Left side = private stakeholder. Right side = Public stakeholders.