HyDelta 2

WP3 – Risks, uncertainty, and collaboration in the hydrogen-based value chain

D3.3 – Individual and system uncertainties in hydrogen value chain developments

Status: final

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Executive summary

Many uncertainties cloud the role that renewable hydrogen may fulfil in the future Dutch energy system. These uncertainties hinder decision-making by public and private stakeholders which leads to a (too) slow uptake of renewable hydrogen in the Dutch energy mix. Investment decisions of individual stakeholders stall due to uncertainties across the value chain from supply to end-use. How to effectively deploy mitigation strategies enabling investment is not self-evident in the multi-stakeholder context of a new value chain such as that of renewable hydrogen.

The main objective of this HyDelta 2.0 research activity was to *enhance the understanding of the impact of risk and uncertainty on stakeholder collaboration and investment decision-making.* The conclusions drawn and recommendations made in this study focus on both the uncertainty identification as well as collaborative mitigation of uncertainties.

The **first** key insight drawn is that the large variety (100+) of investment uncertainties can be structured in a much smaller number of groups. We have identified 11 such groups. Interdependencies between uncertainties in those groups emerge. These uncertainty groups each need to be perceived as collectively acceptable before business cases can turn positive in support of investment decisions.

The **second** key insight illustrates the need to collaborate: Individual investment decision-makers rarely have a direct influence over all these groups of uncertainties. Collaboration between stakeholders along the value chain is required to reduce uncertainty to acceptable levels, enabling more synchronised decision-making.

Addressing uncertainties collectively can be done through deployment of three mitigation strategies:

- **<u>Accept</u>** the presence of the uncertainty to prevent stalling investment decisions
- **<u>Transfer</u>** potential consequences of the uncertainty to stakeholder(s) able and willing to take responsibility for (e.g. governmental bodies). Partial transfer may also be a viable strategy.
- **<u>Reduce</u>** the possibility of occurrence and/or consequence of the uncertainty by sharing the responsibility of preventive mitigation measure deployment and dealing with consequences.

Two recommendations can be considered by value chain stakeholders and Dutch government:
Stakeholders in hydrogen supply chains can follow the Value Network Analysis-based process to identify, (re)distribute and mitigate investment uncertainties. An entity that has the mandate to broker agreements and distribute value, cost, uncertainties and coordinate mitigation measures needs to lead this process to achieve acceptable residual uncertainties in investment decisions of both public and private stakeholders.

Figure 1 5-step process for value chain stakeholder collaboration

Dutch governmental bodies should explore policy concepts that (1) triggers value chain collaboration and (2) aids in mitigating unacceptable uncertainties without an owner that hamper investments.

Samenvatting

De rol die hernieuwbare waterstof kan vervullen in het toekomstige (Nederlandse) energiesysteem is gehuld in veel onzekerheden. Deze onzekerheden belemmeren de besluitvorming door publieke en private belanghebbenden, wat leidt tot een (te) trage opname van hernieuwbare waterstof in de energiemix. Beslisprocessen stagneren door onzekerheden door de gehele waardeketen heen, van levering tot eindgebruik. Effectieve mitigatiestrategieën die investeringen mogelijk maken zijn niet vanzelfsprekend in de multi-stakeholder context van de waterstof waardeketens.

Het hoofddoel van deze HyDelta 2.0 onderzoeksactiviteit was het verbeteren van het begrip welke invloed risico en onzekerheid op investeringsbeslissingen en keten-samenwerking heeft. De conclusies en aanbevelingen in dit onderzoek richten zich zowel op het identificeren van onzekerheden als op het gezamenlijk verminderen van onzekerheden.

Het **eerste** belangrijke inzicht is dat de grote verscheidenheid (meer dan 100) aan investeringsonzekerheden kan worden gestructureerd in een veel kleiner aantal groepen. We hebben 11 groepen geïdentificeerd. Tussen deze groepen zitten onderlinge afhankelijkheden. Deze onzekerheidsgroepen moeten als collectief geaccepteerd worden voordat business cases positief kunnen uitpakken ter ondersteuning van investeringsbeslissingen.

Het **tweede** belangrijke inzicht illustreert de noodzaak om samen te werken: Individuele besluitvormers hebben zelden een directe invloed op al deze groepen van onzekerheden. Samenwerking tussen belanghebbenden in de keten is nodig om de onzekerheden tot een aanvaardbaar niveau terug te brengen opdat een gesynchroniseerder besluitvorming mogelijk wordt.

Het omgaan met onzekerheden kan worden gedaan door de inzet van drie mitigatiestrategieën:

- **Accepteer** de aanwezigheid van de onzekerheid om te voorkomen dat de beslissing stagneert
- De potentiële gevolgen van de onzekerheid **overdragen** aan belanghebbenden die de verantwoordelijkheid kunnen en willen nemen (bijvoorbeeld overheidsinstanties). Een gedeeltelijke overdracht kan ook een haalbare strategie zijn.
- **Verminder** de kans dat de onzekerheid zich voordoet en/of het gevolg ervan door de verantwoordelijkheid van mitigerende maatregelen en het omgaan met gevolgen te delen.

Twee aanbevelingen kunnen worden overwogen door belanghebbenden in de waardeketen en de Nederlandse overheid: **Stakeholders in waterstofketens** kunnen het op Value Network Analysis gebaseerde proces volgen om investeringsonzekerheden te identificeren, te (her)verdelen en te mitigeren. Een bemiddelende entiteit met mandaat is nodig om waarde, kosten en onzekerheden te verdelen en mitigerende maatregelen te coördineren. Dit proces dient om tot aanvaardbare rest-onzekerheden in investeringsbeslissingen van zowel publieke als private belanghebbenden te komen.

Figuur 1 5-stap proces voor waardeketen samenwerking

Nederlandse overheidsinstanties moeten beleidsconcepten verkennen die (1) langdurige samenwerking in de waardeketen op gang brengen en (2) helpen bij het verminderen van onaanvaardbare onzekerheden zonder eigenaar, welke investeringen belemmeren.

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1. Introduction

1.1 Background and context of this research project

Renewable hydrogen and its derived molecules[1] such as renewable ammonia are expected to play a key role in the transition towards climate neutrality in the Netherlands. The North Sea basin offers a vast technical potential for intermittent renewable electricity production which can be used to produce renewable hydrogen. Renewable hydrogen is a natural complement to this renewable source of energy production (see for example GasUnie & TenneT (2019), Berenschot & Kalavasta (2020) and TNO (2020)). Given the urgency of the energy transition, the magnitude of investment needed and the long lead times, the need for renewable hydrogen value chain development is pressing. However, simultaneous acceleration of investments in many supply chain elements is required to move into a more mature phase of the envisioned hydrogen ecosystem.

The current situation

There are a multitude of uncertainties as to how renewable hydrogen may fulfil a role in the future, Dutch energy system. These uncertainties hinder decision-making by public and private stakeholders at the risk of a (too) slow uptake of renewable hydrogen in the Dutch energy mix.

Single-stakeholder investment decisions entail trade-offs between risks and rewards between a limited number of stakeholders. However, investment decision-making processes in new hydrogen value chains involve many stakeholders and are plagued by different types of uncertainties. Arising issues in those value chains will need to be addressed simultaneously to trigger early investment and subsequent scale-up.

The complication of investment decisions

Investment decisions of individual stakeholders often stall due to uncertainties across the value chain from supply to end-use. How to effectively deploy mitigation strategies enabling investment is not self-evident in the multi-stakeholder context of newly to be developed hydrogen value chains.

There is a lack of methods and models to effectively address complex de-risking processes and distribution of investment risks and uncertainties (TNO, 2020) that delays the introduction of hydrogen as a decarbonise in the energy transition.

HyDelta 2.0 Work Package 3 (WP3) aims to identify and assess uncertainties perceived by stakeholders in the value chain. This should facilitate the formulation of a set of recommendations that accelerates the formulation of an effective hydrogen investment policies and strategies of public and private stakeholders. To put WP3 in the context of the HyDelta 2 Project: Work Package 2 (WP2) investigates the optimization of the value of hydrogen in various deployment patterns from a system perspective. In WP3, collaboratively with value chain stakeholders, risks and uncertainties are assessed to understand what hinders investment.

[1] In this report, a clear distinction between hydrogen and its derived molecules in not made, unless explicitly mentioned.

1.2 Introducing the hydrogen value chain and its investment uncertainties

‘Uncertainties’ and ‘risks’ are at the very heart of investment decision-making. Given the specific focus on uncertainties of this report a distinction between the two terms has to be made. The distinct difference between a risk and an uncertainty is whether a probability of occurrence and its corresponding effect thereof can be estimated or not. The classical, well-known theory related to a **risk** says that a risk is an event that has a probability of occurrence and can lead to (a) consequential positive or negative outcome(s) and effect(s). Preferably, this requires historical data of a similar event, or otherwise an analogous event. When there is no knowledge of probability and / or potential outcomes for a given event, the authors consider the event or trend an **uncertainty**. However, the risk vs. uncertainty definition can be considered a grey area [Figure 2].

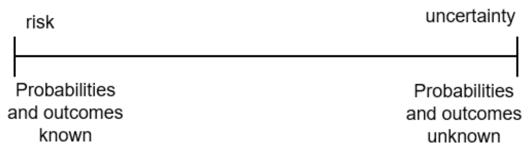


Figure 2 Adapted Risk and Uncertainty Continuum (Casavant, Infanger, & Bridges, 1998)

Inherent ‘uncertainties’ are the topic of this research. Deliverable 3.2 has addressed ‘risk’ extensively.

The focus of this study is to identify these uncertainties within the future hydrogen value chain and assess what mitigation options can enhance investment decision-making. An **investment decision** is defined as a conscious commitment by an organisation to allocate financial resources with the aim to obtain valuable future returns. Such a decision is made based on investment objectives (e.g., monetisation of a competitive position) and an investor’s risk or uncertainty appetite and tolerance. The **hydrogen value chain** encompasses all stakeholders that are part of the value chain. Be it through import, production, policy or any other stakeholder groups. In its most basic design, a hydrogen value chain can be broken down into five main stakeholder groups [Figure 3].

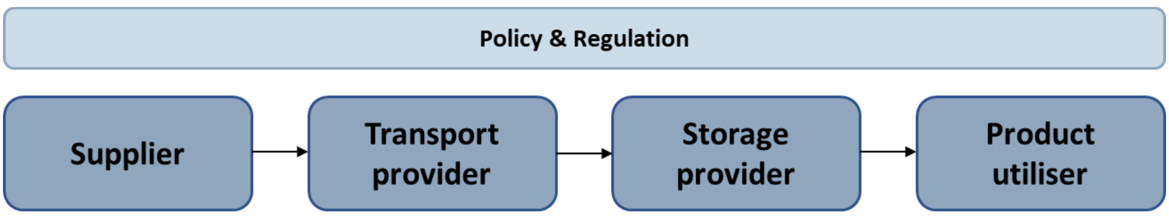


Figure 3 Simplified overview of the five main stakeholder groups within the hydrogen value chain

Clearly, in a new, to be developed market, many stakeholders need to be aligned. The more intricate such a system, the more complicated the decision-making process will be. De Bruijn and ten Heuvelhof (2008) describe that – in an ecosystem with many interdependencies – stakeholders are less successful in solving problems compared to ecosystems with a low number of interdependencies. A key consideration in investment decision-making in, and beyond, hydrogen value chains, is whether and with which level of certainty the cost of resources (mostly spent on the shorter term) is outbalanced by potential returns of value (mostly generated on the longer term).

In the context of a hydrogen value chain, investment decision-making can thereby be conceptualised as an action that, when deployed, enables the transaction of a product or service in exchange for a financial compensation over time. The visualisation of this concept is given in Figure 4. Throughout this report this conceptual view on investment decisions is expanded to include multiple stakeholders multiple value exchanges (3.1) and perceived uncertain events and trends (3.2).

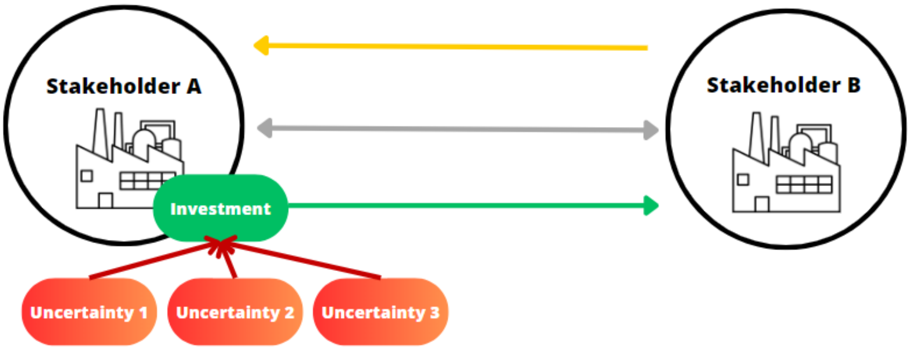
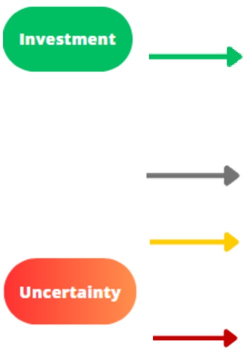


Figure 4 Illustration of an investment decision of stakeholder A based on an envisioned value transaction with stakeholder B and an acceptable level of investment uncertainty

Legend



Stakeholder A **invests in asset(s)** that enable him/her to deploy and operates a new business model and thereby **supplies a product** under the assumption that …
… stakeholder A has the ability to comply with the **exchange-of-value-agreement** made with stakeholder B …
… and the **compensation** received over time justifies the investments in the asset(s).
Investments are inherently **affected by uncertainties** that can directly relate to the value exchange between Stakeholder A and B, or have their origin from value chains and/or systems external to the value exchange.

1.3 Research objectives of HyDelta 2.0 Work Package 3

The overall goal of work package 3 is to increase the understanding regarding the effects of risk, uncertainty and stakeholder collaboration on decisions related to deployment of flexible power-to-hydrogen conversion in energy systems at different levels.

This main goal was divided between three research objectives:

1. Improve understanding of hydrogen generation and demand, transport and storage on market dynamics and the role of related stakeholders”
2. **<u>Enhance the understanding of the impact of risk and uncertainty on stakeholder collaboration and decision-making.</u>**
3. Identify and assess mismatches between individual and system values versus risk.

The main focus of this report is the second objective. To accomplish this objective two research questions are answered in this study:

RQ 3.5 What are main the uncertainties and collaboration mechanisms in hydrogen value chains?

RQ 3.6 What regional (supply chain level) and national (market and policy level) coordination mechanisms will enhance feasibility and facilitate decisive de-risking for the development of hydrogen clusters?

Objectives 1 and 3 are partially addressed in this report and discussed in more detail in HyDelta 2.0 deliverable 3.1 and 3.2.

1.4 Reading guide

This report consists of four parts that each serve their purpose in answering the two research questions. Chapter 1 introduces the context of this research and the research questions that are answered throughout the report. Chapter 2 describes the identification, ranking and interpretation of hydrogen value chain related uncertainties. A proposed method – branded the 5-step process – to value chain related uncertainty management is given in Chapter 3. General conclusions and take-away messages that are given in the final Chapter 4. A visual overview of the project outline is given in Figure 5.

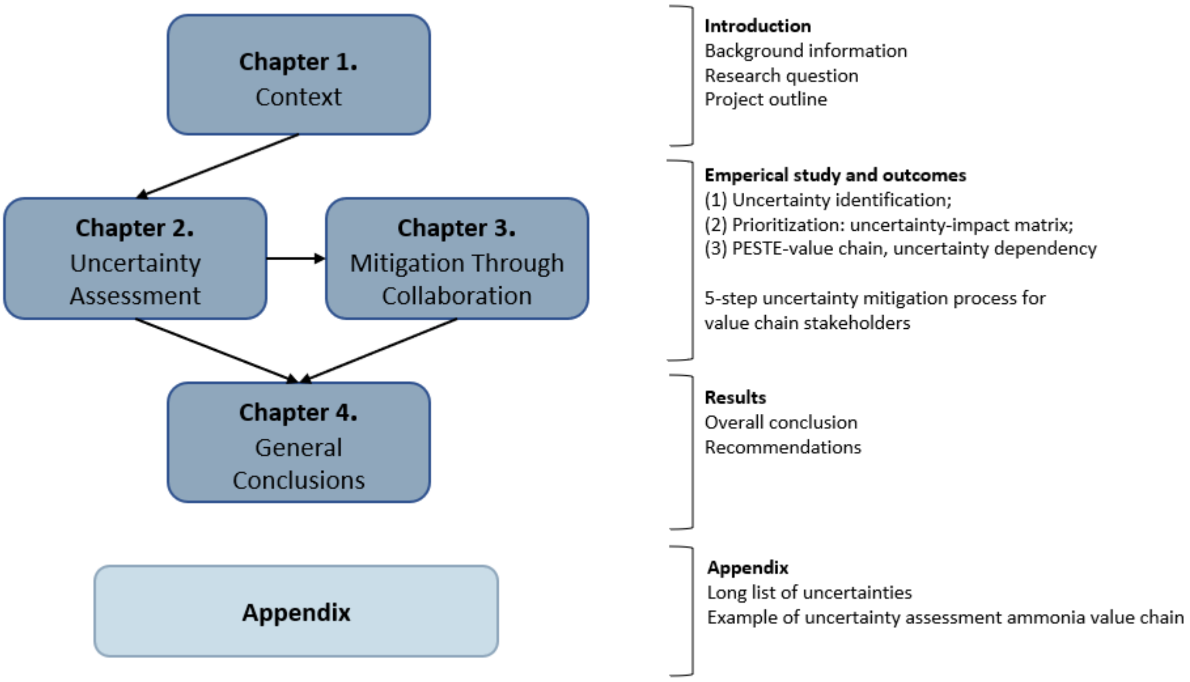


Figure 5 Visual overview of the project outline and the relationships between each chapter

The reader is encouraged to use the conceptual models in this report as inspirational input for their own business operation and investment risk management processes.

2. Assessing uncertainties in hydrogen investment

2.1 Introduction

This chapter focusses on uncertainties hindering investment decisions within the future hydrogen value chain. The key objectives are to identify uncertainties as perceived by industry, policy makers and other stakeholders, prioritize these uncertainties and provide recommendations towards mitigation strategies.

The approach towards the identification and assessment of uncertainty is summarised in Figure 6.

For the execution of step 2 (uncertainty identification) relevant findings related to risks from Deliverable 3.2 of WP3 were taken into account (see Section 2.2). Furthermore, a conversation with public and private value chain stakeholders was designed. Collectively, in a workshop format the most pressing uncertainties were identified (Section 2.3) and prioritized (Section 2.4). The widely shared views collected legitimate the synthesized outcomes and insights presented (Section 2.5) and conclusions drawn (Section 2.6).

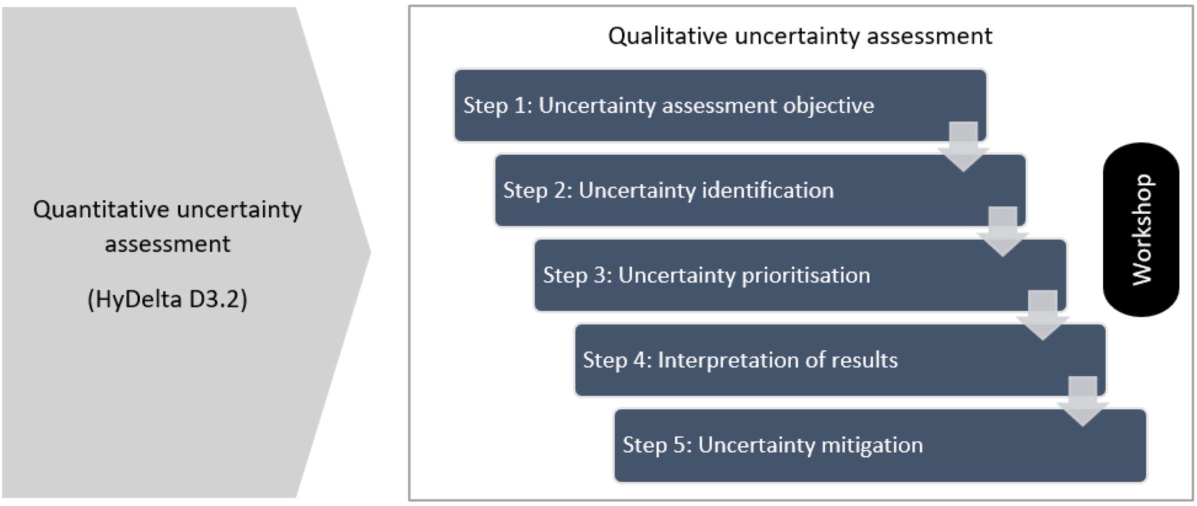


Figure 6 Process followed, considering the most relevant risks from Deliverable 3.2

The objective of the uncertainty objective is to develop a broadened understanding of uncertainties affecting investment decisions in hydrogen value chains which complements the risk assessment conducted in HyDelta 2.0 deliverable 3.2.

2.2 Uncertainty identification: inputs from Deliverable 3.2

As mentioned in chapter 1, a separately conducted study towards risks – rather than uncertainties – has been reported in HyDelta 2.0, deliverable 3.2. Seven risk events were prioritized from this deliverable.

Selected risk events in the risk assessment of D3.2:
1. Outperformed by competitor/competing technology
2. (In)sufficiency of installed technological capacity
3. (Mis)alignment in timing of installed capacity
4. (Non)renewable regulatory status of Dutch Hydrogen
5. Under or over utilization/performance of asset
6. Presence of liquid / open hydrogen market
7. Safety issues with hydrogen technology

The risk assessment insights are used as an input to the subsequent Sections (2.3 onwards). Insights obtained from that study that directly relate to risk events 2, 3 and 5 are transferred to this study. See D3.2 Section 4.2 for more details. Appendix F elaborates in more detail on the distribution network risks discussed below.

- **Large-scale gaseous hydrogen storage**. Storage is a key component of the future hydrogen system, but also a component that is unlikely to materialize before 2030 in the Netherlands unless necessary, additional action is taken. Quantitative modelling shows that storage investment is risky in the early development stages of the hydrogen system. Warranting policy intervention and / or collaboration between market stakeholders are clearly necessary.

- **Import infrastructure (international pipelines, import terminals)**. Like storage, the scale-up of import infrastructure is a risky process, while at the same time it is a mitigation strategy in case of – for instance – high costs of locally produced hydrogen. Since the capacity of import infrastructure is an important feature of a national hydrogen system, coordination between pipeline and terminal development is necessary to make sure that investors do not end up with vast underutilization for a long period of time.

- **Distribution networks.** Construction of distribution networks generally have shorter lead times to those of transmission networks or larger infrastructures (e.g., import terminals). In principle, distribution investments therefore follow other infrastructure investments. Distribution networks may, require the acceptation of the switch from natural gas to hydrogen by all eventual end-users of the repurposed distribution network. The stakeholders that need to collaborate are often of smaller sizes but large in numbers. This implies the need for a substantial coordination effort.

- **Coordination mechanisms for electricity, natural gas and hydrogen transport and distribution.** Today, coordination mechanisms are under development and/or recently introduced for electricity, natural gas and to a lesser extend hydrogen transmission and distribution infrastructure on a cluster (CES), regional (RES) and the provincial scale (PMIEK). However, there is not yet a clear view on to how to resolve very large value chain over-arching risk and uncertainties for – for instance – investors in electrolysis, storage, or hydrogen demand. And such topics are considered difficult to fully capture in coordination mechanisms with clear scopes such as the CES, due to the variety and broadness of those uncertainties and the value chains being part of many different energy sub-systems.

2.3 Uncertainty identification: generation by ecosystem stakeholders

In a full day workshop format with about 40 participants were asked to (1) identify a longlist of hydrogen investment related uncertainties, (2) structure these in groups, and finally (3) prioritize these groups in the most pressing ones. Details regarding the design, process and participants of the workshop can be found in Appendix A.

In order to execute the identification task, open dialogue was stimulated through the application of the “Chatham House Rules”. These imply that neither the name nor the affiliation of a participant can be linked to their provided inputs at the workshop.

The groups were stimulated to use a variety of perspectives in brainstorm sessions as illustrated in Figure 7. From the identification phase a longlist of +160 identified uncertainties was created and included in Appendix B.

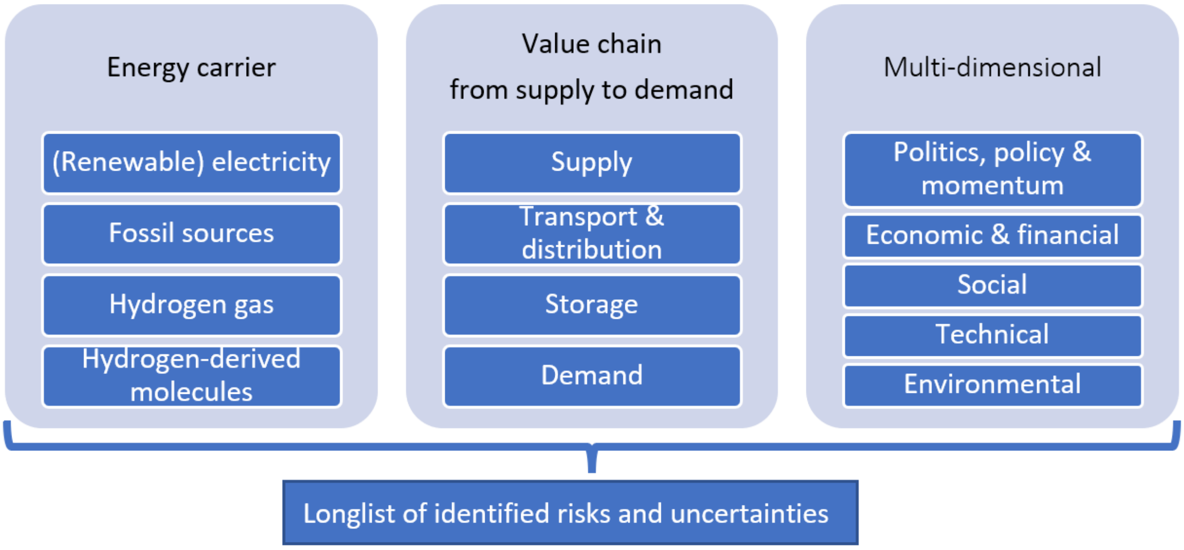


Figure 7 Perspectives offered to participants to facilitate the brainstorm of uncertainties

2.4 Uncertainty prioritization

In step three of the uncertainty assessment process, the list of identified uncertain events and trends were prioritized using the conceptual framework of the *Uncertainty – Impact* matrix, shown in Figure 8. Each event was ranked against these two parameters (one on each axis) in relative terms:

- On the vertical axis, **the extent to which the probability of occurrence of a given event or trend can be determined** is shown. This axis thereby differs from classical probability-impact matrices used in risk management. Uncertainties are positioned in the topside of matrix with their typical characteristics of a probability that is hard or impossible to determine.
- The horizontal axis represents the **estimated impact of events or trends**. Uncertain events may lead to minor or major impact, or the impact may be unknown (not illustrated below).

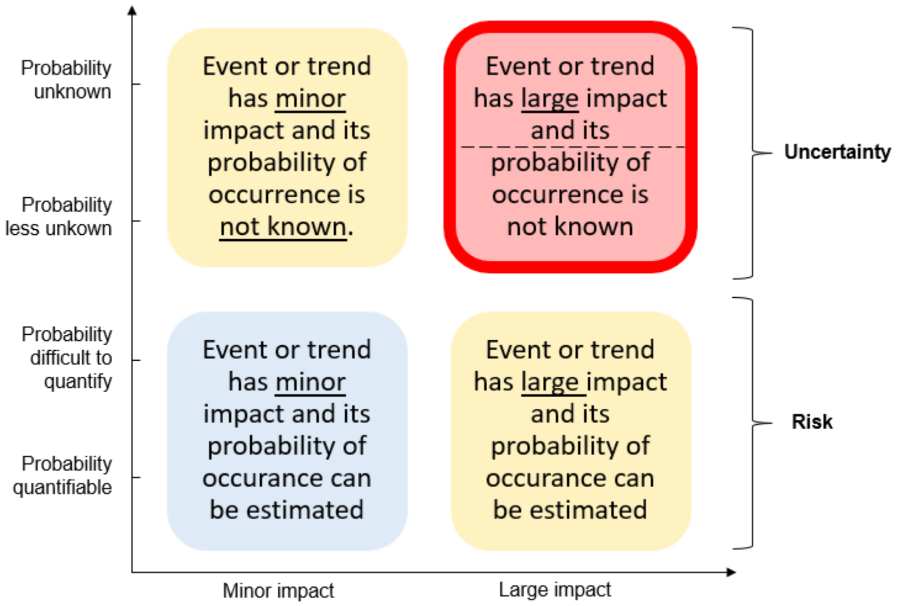


Figure 8 Uncertainty-Impact matrix: Conceptual framework for ranking of uncertainties. Quadrant of interest is top right: high impact and unknown probability

Events or trends ranked in the top-right quadrant, defined as having a high impact but with an unknown probability of occurrence, were prioritized in terms of urgency and therefore focussed on in this study. This quadrant consists of 27 items [Figure 9]. Despite all events being highly uncertain, some uncertainties were judged even more uncertain (top half) than others (bottom half). For example: "*unpredictable volatility and trends in energy markers*" (top right of Figure 9) was judged by the authors to be more uncertain than "*uncertainty about subsidy schemes*" (bottom right of Figure 9). This subdivision between relatively more or less uncertain events or trends enabled the authors to concentrate on those most uncertain events for further processing.

It should be noted, as a disclaimer, that:

- **Biases in the identification and prioritization are inevitable:** Grouping and subsequent prioritization of uncertainties is subject to (unconscious) biases of those executing this structuring. Therefore, the reader is encouraged to perform this grouping and prioritization using the unprocessed list of identified uncertainties themselves;
- **Only top-right quadrant items were assessed**, as others were assumed to have relatively low impact or to be quantifiable.

Figure 9 Content of the top-right quadrant of the Uncertainty-Impact matrix. The dotted line indicates an additional sub selection of uncertainty, with the 11 items above the dotted line classified as the most relevant ones.

2.5 Interpretation and insights: applying the value chain lens

The results of the identification and prioritization step are processed by applying a value chain lens and an uncertainty (inter)dependency lens.

First, the value chain lens is applied. The 27 most relevant uncertainties from Figure 9 are organized in a "Value chain stakeholder-PESTE" matrix which, in addition, also includes the multi-stakeholder category of *chain/system* to be able to categorize those uncertainties that apply to more than one stakeholder [Figure 10].

What stands out when applying this lens is that most of the uncertainties are positioned in the right-hand multi-stakeholder column. This indicates that these uncertainties impact multiple stakeholders at once rather than impacting ''isolated'' stakeholders. Furthermore, uncertainties cluster mostly in the top two rows, hence being of 'policy' or 'economic/financial' nature. These two clusters closely relate to one other: if clarity is generated around politics related uncertainties (such a clear roadmap, policy and subsidy), the uncertainties of economic nature (such as where investments will take place and subsidised income flows) will reduce in terms of probability of occurrence and/or impact.

The **insight** that can be drawn is that for many critical uncertainties, multiple stakeholders will collectively have to find strategies to address these uncertainties.

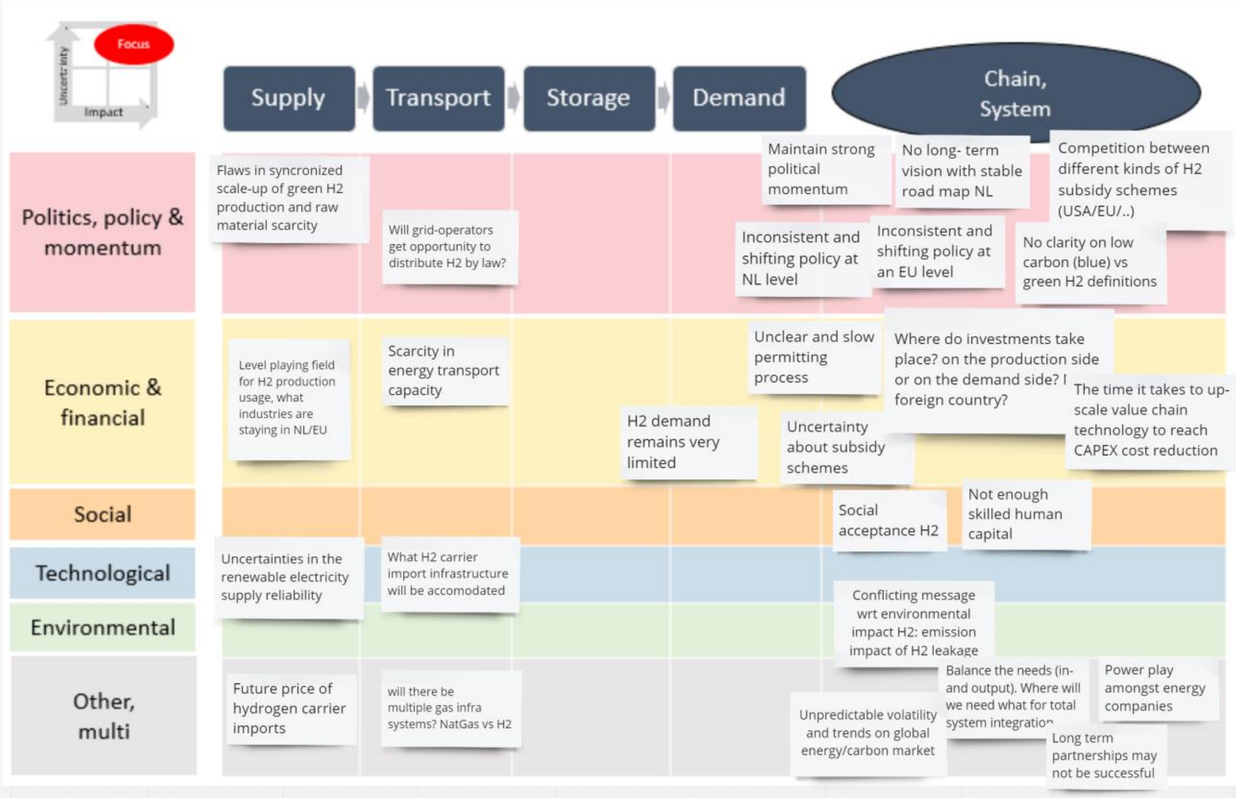


Figure 10 Mapping of the most critical uncertainties against the PESTE dimensions and along the value chain.

2.6 Interpretation and insights: applying the uncertainty dependency lens

Uncertainties can also be organized in terms of their (inter)dependencies. In other words, which group of uncertainties inform, lead to (or critically depend on) other groups of uncertainties. As an example, Section 2.5 already indicated the linkage between "politics" and "economics/financial" groups of uncertainties. In this section, a flow diagram of uncertainty (inter)dependencies was constructed, this diagram sets out to visualise which groups of uncertainties are key bottlenecks hindering attractive business cases and subsequent investments. Note that public investments (e.g., subsidies, compensations) are also considered investment decisions and are thus part of the right side of the diagram.

In order to construct this flow diagram, all uncertainties were grouped. As was mentioned earlier, Appendix B lists all uncertainties and colour codes the grouping. Figure 11 show the resulting groups of uncertainties all the way from global policy themes (on the far left) to regional policy and to the industry themes (on the far right).

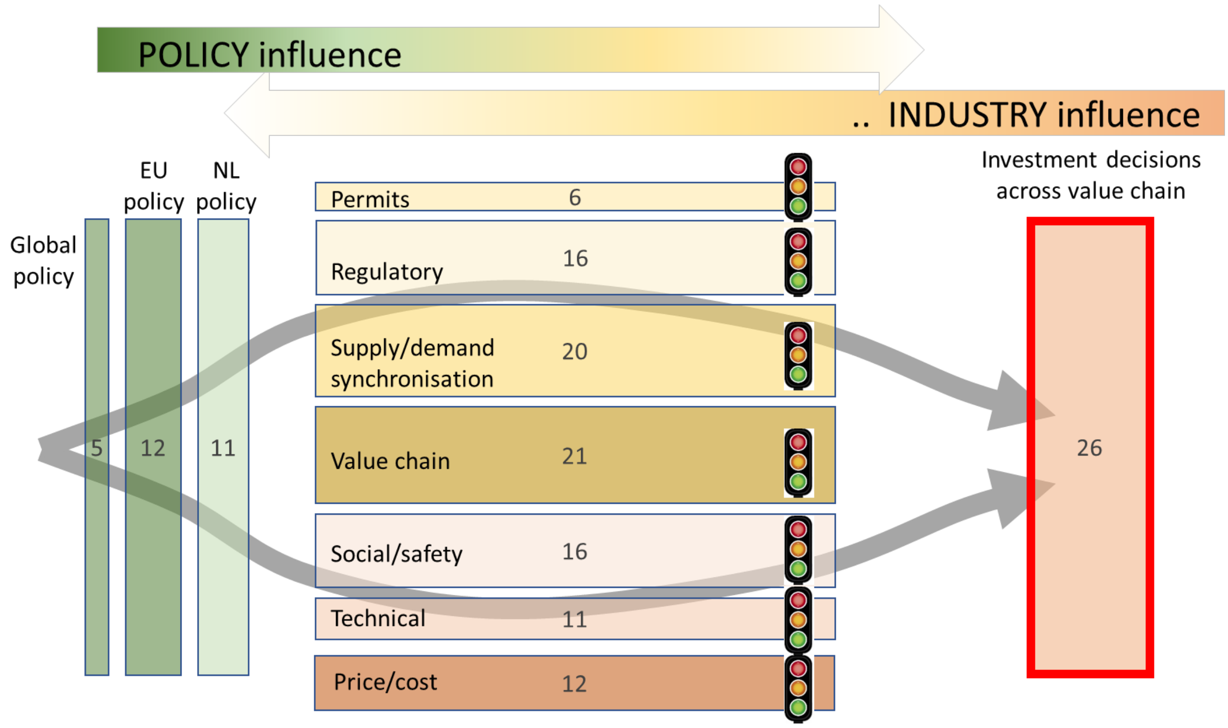


Figure 11 Dependency map of grouped uncertainties. Traffic lights indicate bottleneck groups. Numbers indicate the number of uncertainties in a particular group. Investment decision will only be made if the uncertainties in these bottleneck groups have been resolved.

Figure 11 can be read from left-to-right and vice versa. Exploring only left to right as an example: "Global policy" informs "EU policy" informs "NL policy". Subsequently, "NL policy" informs/influences a set of seven uncertainty groups that need to be handled locally to influence business cases and investment decisions. These seven groups, in turn, ultimately drive uncertainties in the "Investment Decisions" group. Decisions to invest will only be made if first uncertainties in these seven bottleneck groups have been resolved and/or accepted. This is indicated by the traffic light signs.

Two insights were drawn from the uncertainty interpretation step:
1. Specific groups of uncertainties are to be addressed collectively prior to making investment decisions. 2. The comparison of current and previously identified bottlenecks in Dutch energy infrastructure development up to 2030 illustrate that known issues remain unresolved[2]

The **first insight** is that the participants feel that *all* uncertainties in the seven horizontal groups need to be addressed in a collective manner before business cases can turn positive in support of investment decisions. Addressing, in this context, does not necessarily imply that the uncertainties are removed: many uncertainties are too complex to fully mitigate. The known uncertainties per group should be sufficiently understood, mitigated and/or accepted to proceed in the investment decision process. All *"traffic lights*" must thereby turn green (positive) for investment decision-making. And it turning green depends on case-specific stakeholder judgements. Collectively addressing the groups is considered essential as the causes and consequences of many uncertainties reach beyond their allocated single group: Understanding one uncertainty may increase the understanding of the other.

It should be noted that decision-makers will balance short- and long-term risk/uncertainty and value creation (see Section 2.2). The acceptable balance depends on an investor's risk appetite and risk tolerance. An acceptable balance is preconditional to a positive investment decision-making differs for each stakeholder. A parallel is found between the Clear Energy Technology Investment Attractiveness Scan (CETIAS) framework[3] and this study. The CETIAS framework offers a tool to visualise the balance between five groups of risks and uncertainties with potential profits.

A further refinement was obtained using the flow chart as a map for the 11 most critical uncertainties from Figure 11, this is shown in Figure 12. Only seven groups have been highlighted as these contain the largest number of critical uncertainties. The dependency between these uncertainty groups suggests that addressing these uncertainties may need to be prioritized in support of investment decision-making. Note that a single uncertainty (e.g., permit process issue) may block an investment. Each of the seven groups therefore needs addressing.

[2] Energie-infrastructuren 2030: gezamenlijk en afgewogen besluiten is urgent, TNO 2020-R11000
[3] The Clean Energy Technology Investment Attractiveness scan (CETIAS), TNO P12315

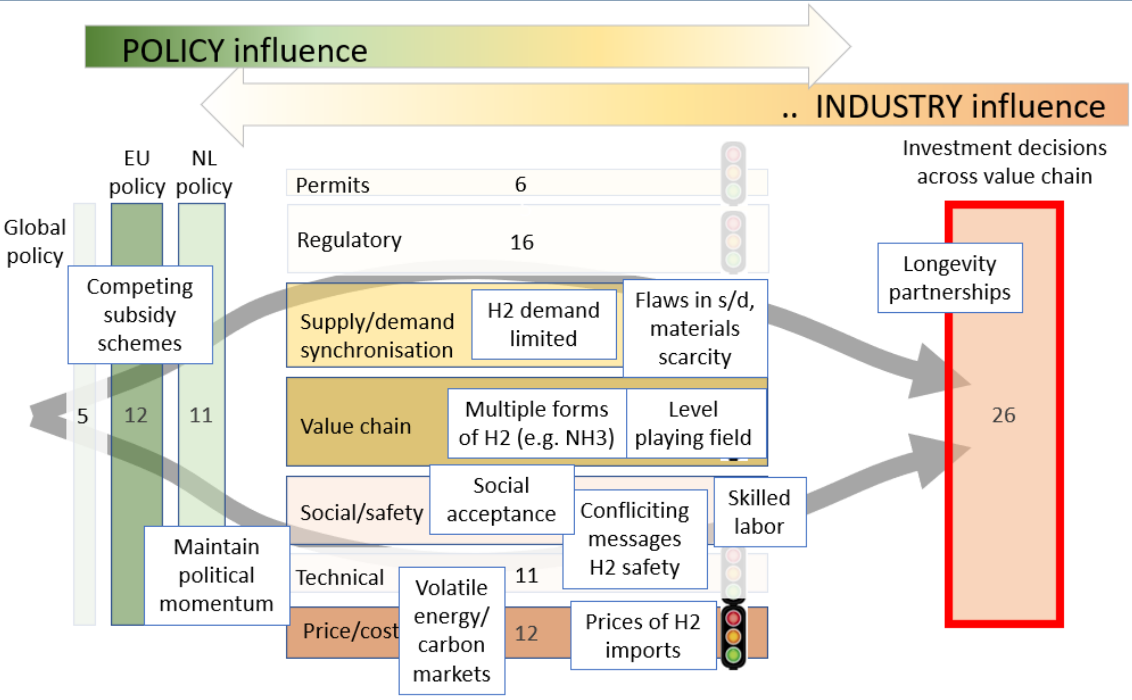


Figure 12 Grouping of the most critical uncertainties identified on the dependency map

The highlighted seven groups are influenced by both policy makers and industry. This reaffirms the insight drawn in Section 2.4, that most uncertainties impact many stakeholders: Hence, policy makers, industry and other stakeholders collaboratively need to address these seven groups of uncertainties.

One could argue that some – if not most – of the critical uncertainties in Figure 12 are 'publicly known open doors'. To put this in perspective, in 2020 the Dutch ministry of Economic Affairs and Climate commissioned a study[4] tasking TNO and partners to identify bottlenecks related to infrastructure required to realise Dutch climate targets by 2030. The study elaborates on three key bottlenecks:

1) **Absence of an energy system overarching perspective**. As an example, this links to a lack of integrated view on the hydrogen and derivatives (such as ammonia or methanol)".
2) **Insufficient availability/transparency of essential data across a value chain**. This hinders different investors in a value chain to simultaneously build attractive "business cases" or the creation of a "level playing field".
3) **Unclarity as to who should carry which risk**. This is perhaps the most relevant one as it touches on most, if not all, uncertainties identified in this report.

The **second insight** therefore is that, based on the obtained insights in this study, there is ground to cover in effectively addressing uncertainties hampering investments required to meet the FitFor55 climate targets[5] despite the efforts made since 2020.

[4] Energie-infrastructuren 2030: gezamenlijk en afgewogen besluiten is urgent, TNO 2020-R11000
[5] Impact 'fit for 55' voorstel voor de herziening RED op de vraag naar groene waterstof in Nederland, TNO 2022 P10151

2.7 Conclusions and recommendations following the uncertainty assessment

Critical uncertainty identification, their subsequent grouping and interdependencies, and their linkages to decision-making leads to the following five conclusions of this chapter:

1. **Investors, do your own re-assessment**: For specific value chains, the identified uncertainties could weigh differently, or other/new uncertainties may drive or hamper decision-making. The reader is recommended to take an active stance towards reviewing the uncertainties provided, to test for relevance/completeness and use in his/her own context of the decision.
2. **Building of a shared view on uncertainties and mitigation**: Decision-making will stall in the absence of clarity as to how uncertainties can be mitigated or exchanged against value. Clarity starts with the building of a shared view on the abstract and subjective topic of uncertainty amongst stakeholders involved in value chains. The subsequent chapter will suggest recommendations on how this could be realised.
3. **Focus first addressing low regret uncertainty mitigation**: Some of the critical uncertainties could be tackled early on – in particular the low hanging fruits – such as the preparing of a master plan for skills build out, or alignment viz-a-viz the prevention of conflicting messages. But also, more difficult to mitigate uncertainties, like whether a particular molecular form of hydrogen will prevail, can perhaps be captured in multi-stakeholder strategies and roadmaps. These could provide clarity to both policy makers and investors.
4. **Organise to win at value chain level**: Changing current value chains or developing new chains requires effective multi-stakeholder collaborations. This requires value chains to get organized. Many organizational forms may be suitable. For example, a joint and mandated private-public entity could be formed to assess value and (re)distribute uncertainty pass through for a given value chain, and act as a broker to align multiple decision-makers across that value chain.

Organise to win at system level: With limited progress made so far – since 2020, the current modus operandi of policy makers on the one hand – and industry on the other hand, seems not as productive as, perhaps, was anticipated. Somehow, all relevant stakeholders need to become organised but are insufficiently triggered to do so. To overcome this impasse, a set of policy concepts explicitly triggering multi-stakeholder collaboration are an obvious means to that end. (Re)organizing the *rules of the game* at the system level should therefore complement the organization of collaborations at the value chain level.

3. A vision and proposal on how to collaboratively mitigate uncertainties

In this chapter a vision is shared, and a complementing method is proposed, to distribute value exchanges and uncertainties amongst hydrogen value chain stakeholders with the aim to make go or no-go investment decisions.

The outcomes and insights of Chapter 3 are elaborated on in the upcoming three paragraphs:

- *Value Network Analysis* is introduced as a tool to facilitate the multi-stakeholder uncertainty identification and mitigation process (Section 3.1)
- Known risk management strategies are introduced and applied to identify *uncertainty mitigation strategies* (Section 3.2)
- A resulting vision and proposed method are introduced and showcased with an example (Section 3.3).
- Policy concept suggestions to trigger value chain collaboration, and residual uncertainty mitigation may be executed, is introduced (Section 3.4).

3.1 Value Network Maps mark uncertainty effects on stakeholder value exchanges

(Future) hydrogen value chains are complex systems with interconnected value chain elements. These value chains involve multiple stakeholders with many specific (interconnected) relationships.

Understanding the interactions between different stakeholders and their respective transaction of values within the value chain is essential to effectively mitigate the potential impact of uncertainties.

To gain insights into these interactions a stakeholder analysis using the *Value Networks Analysis* (VNA) method can be applied. VNA is a tool to systematically analyse the relationships between stakeholders in a network and the values they exchange. VNA was selected to be the most appropriate method for this research purpose. Appendix D discusses other stakeholder analysis methods that were considered in this study.

A *Value Network Map* (VNM) portrays all transactions of tangible and intangible values. A value network helps visualising these different relationships between stakeholders (Allee V. , 2008) which enables stakeholders to discuss and understand their individual roles in the larger context of a value chain/ecosystem. A simplified version of a VNM is given in Figure 13. In reality, the exchanges of values that represent the interaction between stakeholders is more complex.

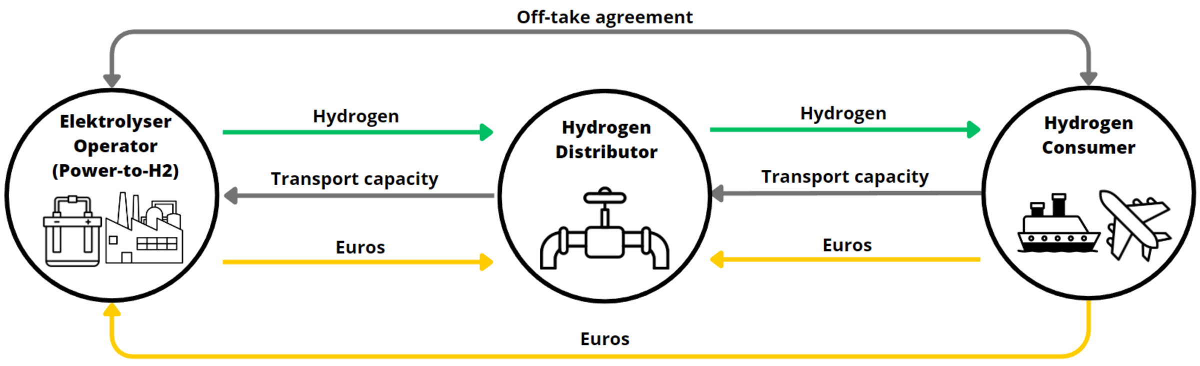


Figure 13 Simplified version of a value network map

Within a value network each “node” portrays a stakeholder or group of stakeholders. The lines drawn between each node depict a transaction of value, be it energy (H_2), financial (euros) or an intangible value such as a contractual agreement or brand reputation. A VNM reveals how stakeholders perceive and exchange value and how changes in, or uncertainties regarding, value influence stakeholder behaviour and decision-making.

While hydrogen products typically move from left to right in the supply chain, each stakeholder representing an element may have a wide range of value exchanges within and beyond this value chain. Investment decisions made by stakeholders in their value chain context therefore require a more elaborate view on value exchanges, interdependencies amongst value chain stakeholders and perceived uncertainties influencing decision-making.

To increase the understanding of a hydrogen value chain and the context in which investment decisions are made, a general overview the Dutch hydrogen ecosystem as a whole, as well as a specific example (bulk NH_3 import case study) is described in Appendix E.

The occurrence of an uncertain event, or the fear of it occurring in the future, can have a decisive impact on value exchanged between directly impacted collaborating stakeholders. As an avalanche, this uncertainty can cascade through the value chain and can thereby also impact decisions of many stakeholders ‘further away’ in the network.

An uncertainty can be regarded as an exchangeable good, similar to a product or a value, and can be passed through from one to another ‘owner’ or shared amongst many owners. Therefore, uncertainty can impact value across the full value chain. Figure 14 depicts a simplified version of a VNM containing a minimal number of stakeholders, in which value, goods and consequences uncertainty are exchanged across value transfer points. The figure illustrates this concept in relation to uncertainty.

- Assume that stakeholder A struggles to decide whether to invest in a service/product supply facility. A guaranteed off take would enable stakeholder A to make a positive decision.
- The service/product cannot be guaranteed (e.g., volume or quality or timing) to pass the value transfer point to stakeholder B
- Therefore, stakeholder B may struggle to determine and commit to financial compensation (such as a price) viz-a-viz the uncertainty in service/product receival.
- Stakeholders A and B will struggle to formalize the agreement unless the uncertainty for stakeholder A is mitigated (with or without the help of stakeholder B).

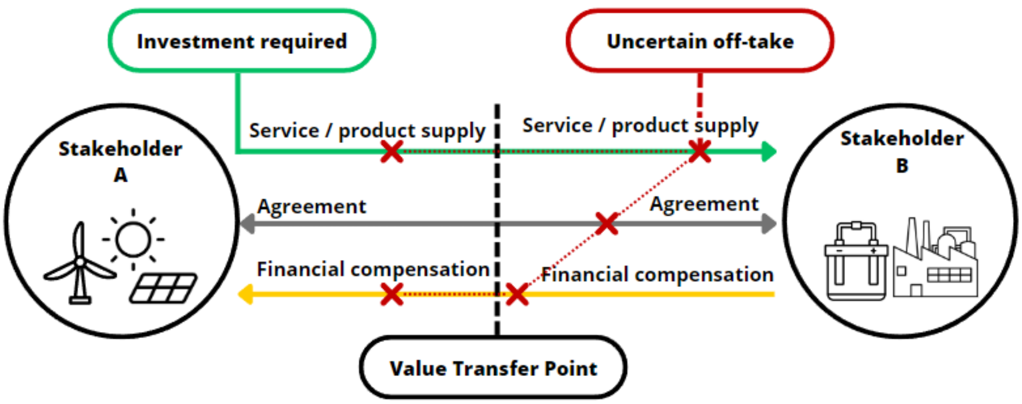


Figure 14 Visualisation of value network value exchange and the cascading effect of an uncertainty

In a new, large and complex system such as the future hydrogen value network, there will be many stakeholders, many value exchanges, and a large variety of uncertain events. The impact of uncertainties could cascade as an avalanche throughout a value network. This cascading effect is more extensively elaborated on in Appendix E which includes the example of one uncertainty (insufficient social acceptance) influences the investment decision of an ammonia import facility, which in its turn influences stakeholders in shipping, fertilizer production and fertilizer end-use.

Mitigation of all possible uncertainties as perceived by all stakeholders in a value chain that may influence their investment decisions can be considered impossible. Each investor therefore reflects on investment decisions from an acceptable uncertainty point of view.

There are, however, options available to investors to appropriately address uncertainties. The next paragraph discusses collaboration of stakeholders with the purpose to mitigate uncertainties.

3.2 Stakeholder strategies need collaboration to mitigate uncertainties

In the mature field of risk management four mitigation strategies are generally considered: A risk event can be accepted or avoided, its impact can be transferred or its probability and/or impact can be reduced. Uncertainty mitigation strategies need a different view on **accept, avoid, transfer** and **reduce.** Table 1 summarizes the applicability of the four mitigation strategies and adds the need to collectively deploy those strategies with the stakeholders in the value chain.

Table 1 Different uncertainty mitigation strategy and their respective collaborative point of views

Uncertainty mitigation strategy		*Multi-stakeholder deployment of mitigation strategy*	*Examples of uncertainty*
Accept	Adapting to the potential consequences of an uncertainty in the future.	Similar to an individual point of view. Note that acceptance of uncertainties by stakeholders may imply transferring impacts of uncertainties to future generation stakeholders and/or stakeholders beyond the line of sight of the group of stakeholders accepting the uncertainty.	Unpredictable volatility and trends on global energy market; power play amongst energy companies
Avoid	The cause of the uncertainty is eliminated entirely.	The uncertainties identified can rarely be avoided in their entirety by mitigation actions that a (group of) stakeholders can take during their investment decisions.	None.
Transfer	The responsibility of dealing with the consequences of an uncertainty are taken over by others.	Formally agree to share the impact of potential consequences amongst multiple stakeholders can be considered a (partial) transfer strategy for an individual stakeholder.	Future price of hydrogen carrier imports; What H_2 carrier import infrastructure will be accommodated.
Reduce	The probability of occurrence and/or the impact is reduced.	Formally agree to share the impact of potential consequences amongst multiple stakeholders can be considered a (partial) reduction strategy for an individual stakeholder. And impact may be reduced by creating optionality advantages through investments in multi-purpose value chains.	Not enough skilled human capital; Unclear and slow permitting process.

Mitigating investment uncertainties can be done by deployment of three strategies

- **Accept** the presence of the uncertainty to prevent that uncertainty from stalling the investment decision.
- **Transfer** potential consequences of the uncertainty to stakeholder(s) able and willing to take responsibility for (e.g. governmental bodies). Partial transfer may also be a viable strategy.
- **Reduce** the possibility of occurrence and/or consequence of the uncertainty by sharing the responsibility of preventive mitigation measure deployment and dealing with the consequences when they unfold.

Identifying and mitigating uncertainties collaboratively as a group of impacted stakeholders enables those stakeholders to:

- **Increase their ability to understand**, foresee and explore different future scenarios in which uncertainties have, or have not, impacted the current state of the world (e.g., combine complementing knowledge and world views on the current and future state of the world by reducing biases. What may be an uncertainty for one stakeholder, may merely be a risk to the other).
- **Increase the yield of individual mitigation efforts** by coordinated and larger-scale actions (e.g., influence the public debate or public opinion).

Many forms and mechanisms of multi-stakeholder collaboration exist to collaboratively create value chains and mitigate uncertainties. The suitable form/mechanism of collaboration will depend on the uncertainty to be mitigated and is an extensive field of study. Examples of multi-stakeholder collaboration mechanisms can be found in (de Bruijn & ten Heuvelhof, 2008), (Allee V. , 2008), (Howlett, 2007), (DRIFT, 2023).

Paragraph 3.4 illustrates, by means of an example, how collaborative uncertainty mitigation may be coordinated at a (regional) supply chain level.

3.3 5-step process for value chain stakeholder collaboration and the need for coordination

Currently there is no guideline or mechanism that offers a set of ‘rules’ regarding as to how uncertainties related to renewable hydrogen value chain could be mitigated through collaborations.

Such a mechanism would need to address at least three elements (TNO, 2020):

- Alignment of stakeholder interests **across the value chain.**
- Alignment of the **timing** of investment decisions and the related **ownership** of uncertainties.
- Alignment of **cost and value versus uncertainties** amongst stakeholders.

A vision and proposal as to how such a mechanism could be crafted and its functioning is shared below. This proposal expands on the fundamentals of TNOs Innovation Orchestrating approach to facilitate multi-stakeholder collaboration[6].

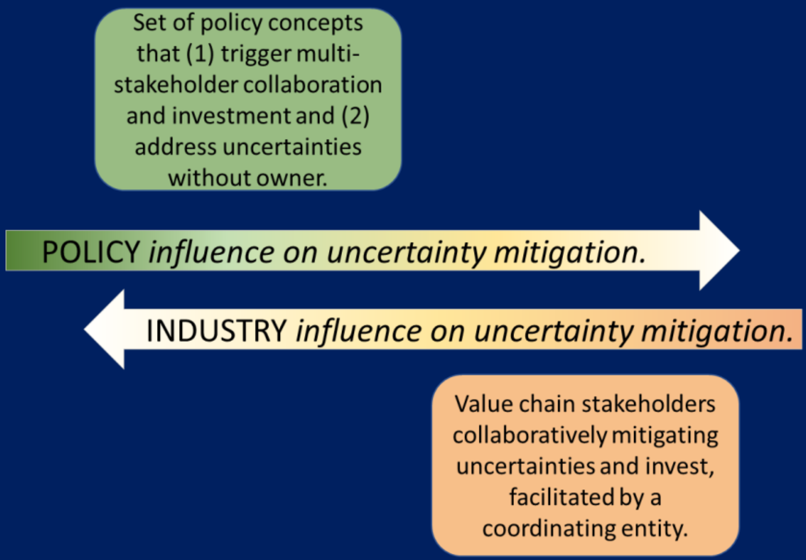
[6] https://orchestratinginnovation.nl/

A vision on uncertainty mitigation

Balancing advantages and disadvantages for each stakeholder in the value chain requires a collective understanding of uncertainties, their potential impact on value exchanges, and how the ownership of uncertainties and corresponding mitigation strategies could be shared/distributed.

A group of value chain stakeholders willing to collaboratively mitigate their investment uncertainties requires an independent and mandated coordinating entity to guide those stakeholders towards their common goal: acceptable costs, benefits and uncertainties for all.

This type of multi-stakeholder collaboration does rarely materialize without a trigger. And unacceptable uncertainties hampering investments will require the absorption and/or mitigation strategies by governmental bodies. In addition to the coordinating entity at the value chain level, the supporting policy concepts to trigger collaboration and overcome uncertainties without an explicit 'owner' is deemed a critical success factor to enable investment decisions and realize renewable hydrogen value chains.



Industry-driven uncertainty mitigation possibilities through stakeholder collaboration, and government-driven policy frameworks are envisioned to complement one another. The focus in this paragraph is on the value chain collaboration. In paragraph 3.4, the policy framework is briefly introduced.

Coordination within value chains to enable stakeholders to invest is to be organized in order to overcome a variety of value chain-level uncertainties and thus decision paralysis situations. The subsequent 5-step approach to collaborative uncertainty mitigation and investment in a value chain illustrates, based on the obtained insights throughout this study, how such a coordination process could look like. Given the diversity of stakeholders and corresponding stakeholder interests, one coordinating entity to facilitate the collaborative process is assumed to be present.

Step 1: Value Network Map

- Develop a **Value Network Map** on which the stakeholders in the value chain of interest and the value exchanges between stakeholders are made explicit.

Step 2: Uncertain events and trends

- Identify **uncertain events and trends** that may impair or enhance the values to be exchanged between stakeholders.

Step 3: Investment attractiveness gaps

- Discuss and conclude on the **gaps in perceived uncertainty levels and uncertainty acceptance** of the individual stakeholders.

Step 4: Distinguish, select and mitigate uncertainties

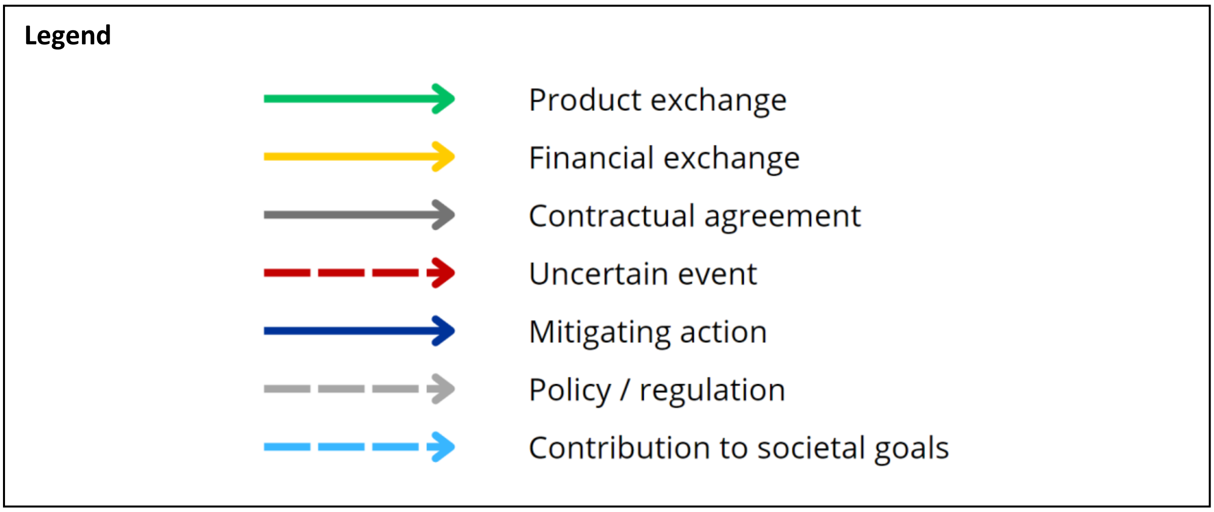
- Distinguish between **individual and collective uncertainties,** select and **mitigate uncertainties with stakeholders involved** through collaborative measures and/or re-distribution.

Step 5: Expand value network

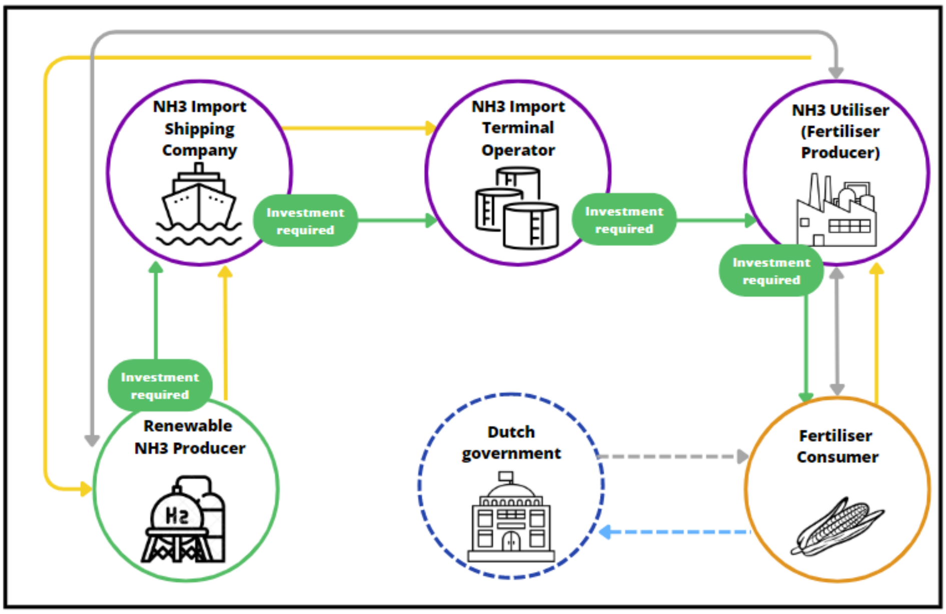
In case of unacceptable residual uncertainty gap(s): **Expand the Value Network** with additional stakeholders that can assist in the collective uncertainty mitigation process and

To demonstrate the proposed process a simplified example of step 1-5 is presented based on the detailed content of the previous chapters.

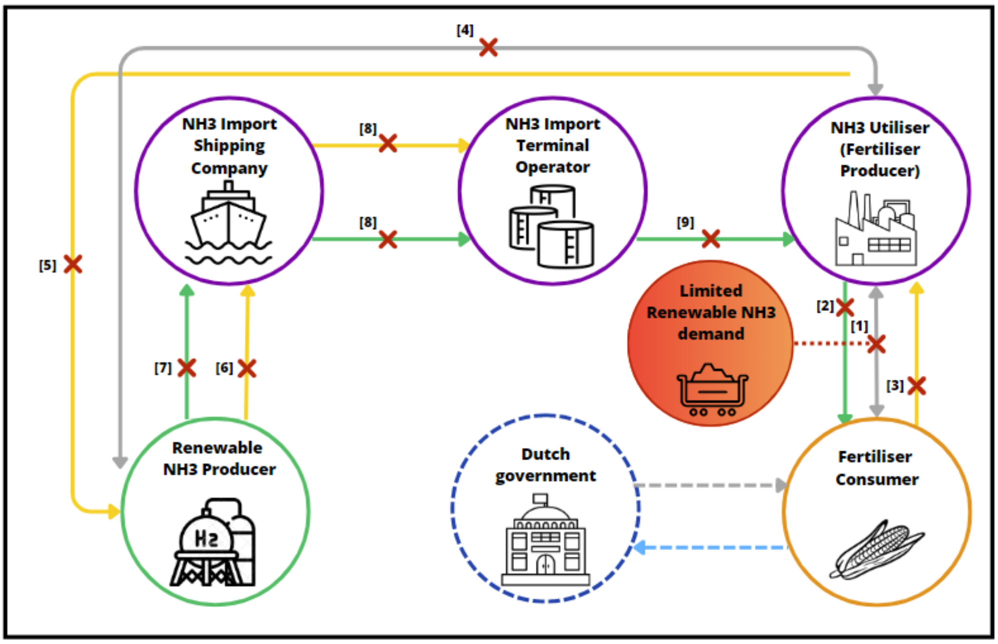
The following legend can be used to understand the demonstrative figures throughout the examples:



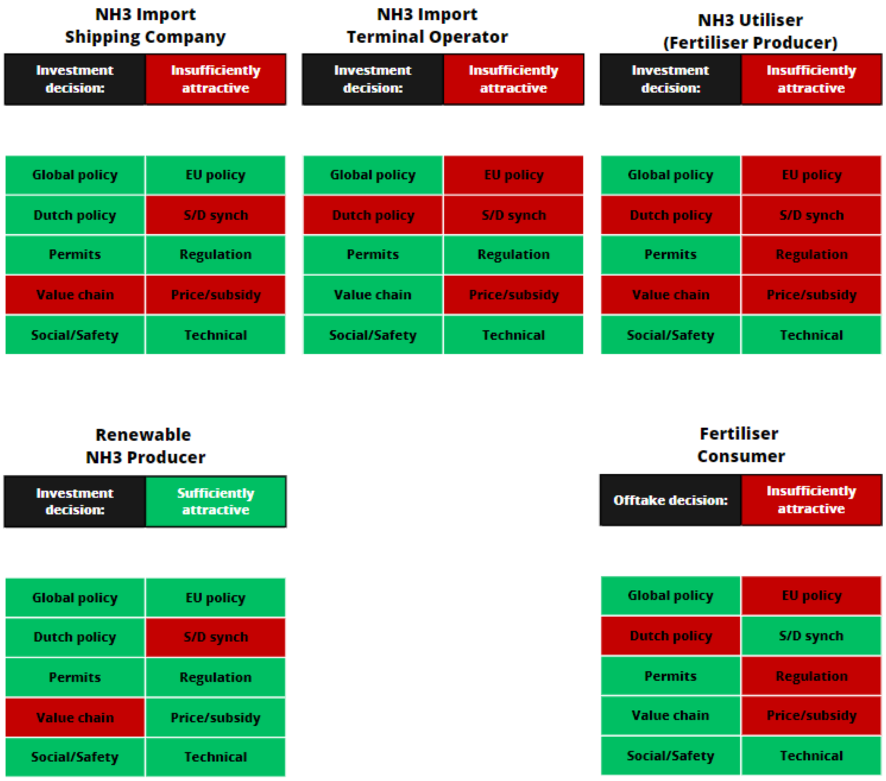
<table>
<tr><td>Step 1</td><td>Develop Value Network Map (VNM) & determine investment decisions</td></tr>
<tr><td>Goal</td><td>Create mutual understanding amongst stakeholders which values are exchanged, and which investment decisions are to be taken.</td></tr>
<tr><td>Approach</td><td>1. Bring together the stakeholders that are part of the value chain of interest. Minimise the amount of stakeholders initially (see step 5).
2. Identify the value exchanges between those stakeholders.
3. Include the investment decisions to be taken per stakeholder.</td></tr>
<tr><td>Example</td><td>A simplified VNM of renewable ammonia (NH_3) production, import, offloading, conversion to fertilizer and consumption of fertilizer is presented as an example for step 1. Investment decisions per stakeholder are:
- Renewable NH_3 producer: Investment in production capacity is assumed. NH_3 off-taker may also be found in other value chains.
- NH_3 import shipping company: Invest in NH_3 import ship to accommodate NH_3 transport from NH_3 producer to NH_3 import terminal operator.
- NH_3 import terminal operator: Invest in new capacity or increase capacity of existing terminal.
- NH_3 utilizer (Fertilizer producer): Invest in new capacity or increase capacity of existing fertilizer production process.
- Fertilizer end-user: no investment is assumed as fertilizer purchase relates to operational costs only.



<u>Note</u>: the Dutch government is added as an additional stakeholder in step 5 of the process.</td></tr>
</table>

<table>
<tr><th>Step 2</th><th>Identify uncertain events and trends & map their effect on value exchanges</th></tr>
<tr><td>Goal</td><td>Create mutual understanding amongst stakeholders regarding the perceived uncertainties and their potential consequences on value chain performance.</td></tr>
<tr><td>Approach</td><td>1. Identify uncertainties that (in)directly influence investment decisions
2. Plot uncertainties in VNM and allocate those uncertainties to a single (primary) affected value exchange.
3. Add the cascading consequential effects per uncertainty on value exchanges throughout the rest of the value chain.</td></tr>
<tr><td>Example</td><td>The uncertainty identification of Chapter 2 illustrates the diversity of uncertainties that are identified by a diverse group of hydrogen value chain stakeholders. One uncertainty is selected from Section 2.4 and tailor-made for step 2: Limited demand for renewable hydrogen-based fertilizer products by end-users.
The cascading effects of the uncertainty are illustrated and described below.


Primary affected value exchange:
1. Fertilizer end-user offtake from renewable fertilizer producer is uncertain.
Consequentially affected value exchanges:
2. The volume of fertilizer to be supplied by the NH_3 utilizer is uncertain.
3. Financial compensation from Fertilizer end-user to NH_3 utilizer in exchange for the renewable fertilizer is uncertain
4. The contracted volume of NH_3 to be purchased by via NH_3 utilizer through NH_3 import vessel is uncertain.
5. The ability to provide financial compensation for the NH_3 imported by the NH_3 utilizer to NH_3 importer is uncertain.
6. The transport capacity of the NH_3 import shipping company for this specific value chain is uncertain.
7. The financial compensation from NH_3 producer for using the NH_3 import shipping company service is uncertain.
8. The import capacity of the NH_3 import terminal for this specific value chain is uncertain.
9. The financial compensation from NH_3 for using the NH_3 import terminal service is uncertain.</td></tr>
</table>

<table>
<tr><th>Step 3</th><th>Investment attractiveness gaps in value chain</th></tr>
<tr><td>Goal</td><td>Create mutual understanding amongst stakeholders which investments are insufficiently attractive and why.</td></tr>
<tr><td>Approach</td><td>
1. Conclude longlist of cascading effects from all uncertainties identified affecting individual stakeholder investment decision
2. Share acceptable levels of uncertainty per stakeholder (for each of the 12 uncertainty groups and cumulatively).
3. Discuss and conclude on the gaps in perceived investment attractiveness of individual supply chain stakeholders.
</td></tr>
<tr><td>Example</td><td>
An example of the longlist of cascading effects is included in Appendix E.
The perceived acceptance levels of uncertainty per stakeholder is simplified below in accordance with the 11 uncertainty groups discussed in Section 2.6.
- Renewable NH_3 producer: Investment in production capacity is perceived <u>sufficiently attractive</u> despite offtake uncertainty in the value chain of interest due to other NH_3 value chain off-taker presence.
- NH_3 import shipping company / import terminal operator: Uncertainty regarding offtake agreement between NH_3 producer and NH_3 utilizer leads to an <u>unattractive</u> investment proposition for additional import shipping / terminal capacity.
- NH_3 utilizer (Fertilizer producer): Uncertainty regarding renewable fertilizer demand by fertilizer end-user leads to <u>unattractive</u> investment proposition for additional NH_3-to-fertilizer production capacity.
- Fertilizer end-user: Switching from current (fossil-based) to renewable fertilizer offtake is <u>perceived unattractive</u> due to the absence of regulatory and financial incentives.


</td></tr>
</table>

<table>
<tr><th>Step 4</th><th>Distinguish, select and mitigate uncertainties</th></tr>
<tr><td>Goal</td><td>Create mutual understanding and agreement amongst stakeholders which uncertainties can be mitigated by whom.</td></tr>
<tr><td>Approach</td><td>1. Collectively decide which uncertainties can/cannot and should/should not be mitigated to close all investment attractiveness gaps of the value chain investors involved.
2. Define and deploy mitigation strategies collectively with impacted stakeholders: Accept, Transfer or Reduce.
3. Re-assess the balance of value exchanges and perceived uncertainties per investor.
4. Take investment decisions, decide not to invest, or proceed to step 5.</td></tr>
<tr><td>Example</td><td>The initial mitigation strategy to address the selected uncertainty, limited demand for renewable hydrogen-based fertilizer products by end-users, is defined as:

• Establish alignment of supply-demand synchronisation required between NH_3 utilizer and Fertilizer end-user. Two strategies are deployed in parallel:

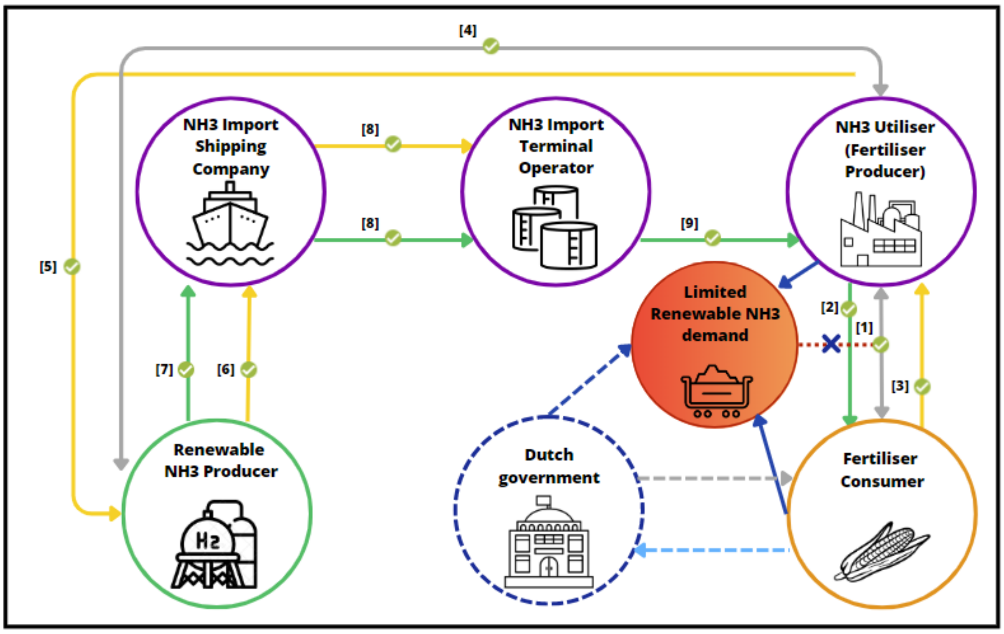
<table>
<tr><th>Initial actors:</th><th>Mitigation strategy</th><th>Effect on uncertainty</th></tr>
<tr><td>NH3 utilizer (Fertilizer producer) & Fertilizer end-users</td><td>Negotiate long-term renewable hydrogen-based fertilizer supply agreement(s) with multiple fertilizer end-users reduces dependability on few offtakers.</td><td>Uncertainty reduction regarding offtake volumes of NH3-based product leads to acceptable uncertainty level in volume flow and financial return. Residual uncertainty relates to, for example, potential bankruptcy of offtakes.</td></tr>
<tr><td>Fertilizer end-user & NH3 utilizer</td><td>Negotiate long-term renewable hydrogen-based fertilizer supply agreement(s) with (multiple) NH3 utilizer(s) reduces volume and price uncertainty and transfers availability uncertainty from end-user to supplier.</td><td>Guaranteed supply reduces uncertainty in availability and increases long-term fertilizer purchase cost projection. Residual uncertainty may be related to the ability to maintain competitive in level playing field and corresponding ability to remain financial health.</td></tr>
</table>

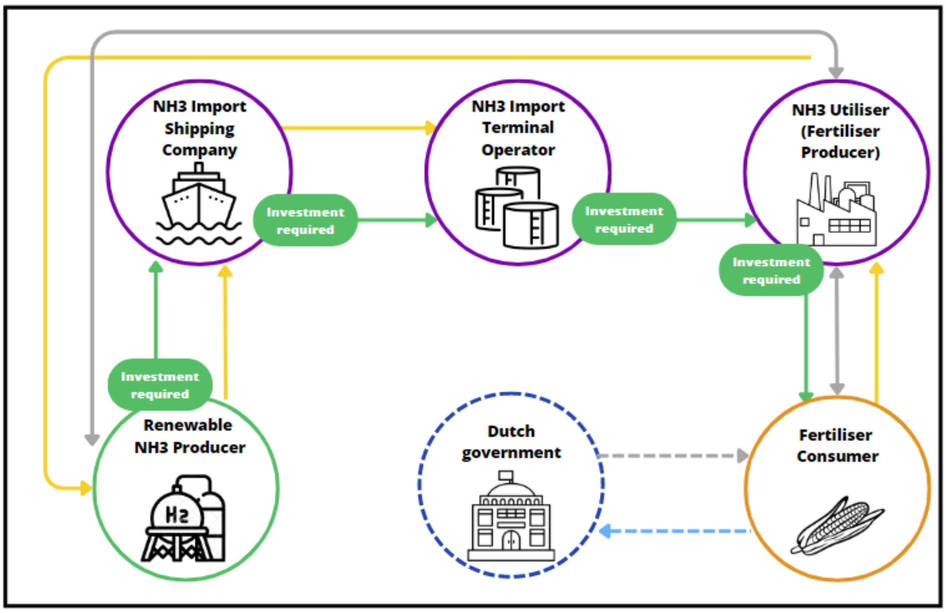
• After step 5, a third mitigation strategy is introduced: Governmental policy development to provide clarity on long-term offtake needs for NH_3 utilization and fertilizer end-use.

<table>
<tr><th>Additional actor:</th><th></th><th></th></tr>
<tr><td>Dutch government</td><td>Develop carrot and stick policies to increase end-user demand for renewable hydrogen-based fertilizer products over time.</td><td>Uncertainty on green NH3-based fertilizer offtake volume requirement development over time is reduced. Initially for Fertilizer end-users and consequentially for all other stakeholders in the value chain.</td></tr>
</table>

The effects of the three mitigation strategies on each value exchange in the VNM are illustrated below. The blue lines depict the mitigation strategies.

The cumulative effect of the mitigation strategies may change unattractive decisions into attractive ones, when deployed in harmony. Collectively, all investment decisions may now be positively taken.</td></tr>
</table>


[4]
NH3 Import Shipping Company
[8]
[8]
NH3 Import Terminal Operator
[9]
NH3 Utiliser (Fertiliser Producer)
[5]
Limited Renewable NH3 demand
[2]
[1]
[3]
[7]
[6]
Renewable NH3 Producer
H2
Dutch government
Fertiliser Consumer

Step 5	Expand the Value Network if needed
Goal	Develop a coalition of stakeholders that can collectively achieve positive investment (and/or policy) decisions in each supply chain element.
Approach	In case of unacceptable residual risk gap(s) the Value Network is (are) to be expanded with additional public and/or private stakeholders to assist in the collective uncertainty reduction process. 1. Identify additional stakeholders that may be able and willing to reduce unacceptable residual uncertainties (step 4). 2. Repeat Steps 1-4. 3. If residual uncertainties are insufficiently mitigated, repeat step 5. Note: minimize the stakeholders in the Value Network continuously to minimize the interests that are to be met. Complexity increases are non-linear when stakeholders are added.
Example	A Dutch governmental body is added to the VNM. A relationship between the government and fertilizer consumer is introduced increasing the demand for renewable fertilizer demand by means of a stimulation or enforcing policy. Renewable fertilizer offtake should thereby be substituting fossil-based fertilizer offtake. The uncertainty 'Limited demand for renewable hydrogen-based fertilizer products by end-users' is thereby reduced. The 'societal goal contribution' relationship of fertilizer consumers towards the Dutch government illustrates the contribution to environmental impact reduction related to fertilizer end-use. The Dutch government contributes to uncertainty reduction on top of other uncertainty mitigation strategies (see step 4). 

3.4 Policy options to getting organized and mitigate uncertainties that have no owner

The fifth conclusion of Chapter 2 states that policy concepts triggering multi-stakeholder collaboration are an obvious means to that end. This paragraph briefly introduces design suggestions for such a triggering policy framework.

Investment will only happen when expected benefits outweigh the impacts of perceived uncertainties. For hydrogen value chains, business cases carry high levels of uncertainty and, consequently, market participants hesitate to invest on a large scale. This situation is a typical example of a classic market failure that can be repaired by intervention of governments. An effectively designed role of governments to trigger scale up private (collaborative) investments most likely needs a blend of various interventions.

Governments typically intervene by means of policy instruments, which consist of a wide range of possible instruments. In principle, four different types of policy instruments and mechanisms can be distinguished (Hoogerwerf & Herweijer, 2008; Poel & Kool, 2008):

1. Financial-economic incentives, including subsidies and levies;
2. Public facilities, such as infrastructure works;
3. Education and other types of information transfer;
4. Prescriptions, including laws and regulations.

The actual implementation of these instruments in turn has four control concepts:

A. Hierarchical steering, in which the government imposes rules of conduct from above;
B. Self-management within frameworks, in which the government imposes preconditions, but citizens and organizations still have room for their own choices;
C. Interactive policymaking, in which agreements are made with citizens and organizations about behavior
D. Network management, in which the government acts as a broker and switcher to bring parties together.

Each combination of instrument and steering concept produces a so-called policy concept. Table 2 shows the overview of the 16 policy concepts. For a detailed description, see Hendriksen (2010).

Table 2 Matrix of different instrument types and coordination concepts, containing concrete policy interventions

	Hierarchical steering	Self-management within frameworks	**Interactive policymaking**	Network management
Financial-economic incentives	Taxes and duties	Generic subsidies	**Targeted subsidies**	Public/governmental procurement
Public facilities	Institutional investments	Privately executed public functions	**Public-private partnership**	Networks and platforms
Education	Propaganda	Informing	**Direction**	Advising and consulting
Prescriptions	Laws and regulations	Frameworks and goals	**Covenants**	Labels and standards

In order to trigger investment in hydrogen value chains, multi-stakeholder collaboration needs to be established to reduce perceived uncertainties to acceptable levels. Current incentives alone can be considered insufficient. Several of the given policy concepts could make collaborations come about. These are mostly part of, but not limited to, the ***Interactive Policy-making control concept***. Examples of policy instruments thus are the creation of public-private partnerships, perhaps through covenants and financially supported by specific subsidies (for example, to guarantee hydrogen prices or hydrogen off-take).

Given the urgency of achieving climate goals in conjunction with unprofitable business cases an active role of the government and hence an enhanced version of the Interactive Policy-making control concept is required, complemented by policy concepts from other control concepts (e.g., labels and standards, laws and regulations and institutional investments. And such a complex policy framework design and implementation does not come about easily.

The assessed investment uncertainties in this study may prove useful input to future research and development in this policy framework. Investment uncertainties that cannot be allocated to, or mitigated by, a single or combination of value chain stakeholders will need to be accepted by the investors or mitigated and/or absorbed by governmental bodies.

3.5 Conclusions on collaborative uncertainty mitigation in value chains

Investment decisions need acceptable distributions of value exchanges and uncertainties amongst hydrogen value chain stakeholders. A value that is exchanged between stakeholders can have many forms: products, services, financial compensation, environmental impact reduction, guaranteed supply agreement, et cetera. And, as Chapter 2 extensively illustrated, uncertainties exist in many forms as well. When value exchanges are subjected to unacceptable levels of uncertainty, investment decisions may not be taken.

Understanding the interactions between different stakeholders is essential to be able to identify the possible direct and indirect consequences of uncertainties that may affect value chain performances. The collectively increased understanding amongst value chain stakeholders can potentially aid in the mitigation of these uncertainties.

A vision on collaborative uncertainty mitigation strategies is developed:

A vision on uncertainty mitigation
Balancing advantages and disadvantages for each stakeholder in the value chain requires a collective understanding of uncertainties, their potential impact on value exchanges, and how the ownership of uncertainties and corresponding mitigation strategies could be shared/distributed. A group of value chain stakeholders willing to collaboratively mitigate their investment uncertainties requires an independent and mandated coordinating entity to guide those stakeholders towards their common goal: acceptable costs, benefits and uncertainties for all. This type of multi-stakeholder collaboration does rarely materialize without a trigger. And unacceptable uncertainties hampering investments will require the absorption and/or mitigation strategies by governmental bodies. In addition to the coordinating entity at the value chain level, the supporting policy concepts to trigger collaboration and overcome uncertainties without an explicit 'owner' is deemed a critical success factor to enable investment decisions and realize renewable hydrogen value chains.

And a 5-step process for uncertainty mitigation strategy development is discussed that could lead to acceptable residual uncertainty in investment decisions of public and private stakeholders:

Step 1: **Value Network Map**

Step 2: **Uncertain events and trends**

Step 3: **Investment attractiveness gaps**

Step 4: **Distinguish, select and mitigate uncertainties**

Step 5: **Expand value network**

For a new hydrogen-based value chain, the primary challenge is to synchronise decision-making of multiple stakeholders collectively. This can only be done when uncertainties are reduced or mitigated to the extent that risks and uncertainties are balanced by potential profits. This required balance is characterized by the stakeholder-specific level of acceptable uncertainty.

4. Overarching conclusions and recommended next steps

To meet the overarching objective of this research project, enhancing the understanding of the impact of risk and uncertainty on stakeholder collaboration and decision-making, the following two questions have been answered in this report:

- What are main risks, uncertainties, and collaboration mechanisms in hydrogen value chains?
- What regional (supply chain level) and national (market and policy level) coordination mechanisms will enhance feasibility and facilitate decisive de-risking for the development of hydrogen clusters?

The majority of the effort of this study focused on the identification of the most relevant uncertainties and the impact of their occurrence on public and private investment decisions. Over 100 uncertainties were identified and clustered in 11 themes. Investment decisions require acceptable mitigation of uncertainty in at least 7 out of 11 themes.

It became clear that a closer collaboration between value chain investors and policy makers to address uncertainties is necessary. In particular, attention is to be given to balance costs, value, risks and uncertainties of investments in large storage, import infrastructure, distribution and transmission networks due to their preconditional role in value chains. The task ahead is to create a common understanding of risk and uncertainty and how these are to be distributed or shared between investors in the value chain as well as with policy makers.

The recommendation is made in Chapter 3 to adopt the Value Network Analysis (VNA) method to distribute uncertainty mitigation responsibilities. VNA was deployed as a means to create a common and transparent understanding of how value exchanges between stakeholders, and the impact of uncertainties on those value exchanges can be visualised, understood and perhaps even be accepted, transferred and/or reduced throughout the value chain. If done in a just and collaborative manner, investment decision-making throughout a value chain can be enhanced by realisation of acceptable balances of cost, value creation, risk and uncertainty ownership per stakeholder.

Such synchronised investment decision-making requires coordination. Prerequisites for successful collaboration includes, but is not limited to, an independent entity that has the mandate to broker agreements and distribute value, cost, uncertainties and coordinate mitigation measures.

In addition, policy concepts are required that trigger value chain stakeholders to collaborate, accept a coordinating entity, mitigate uncertainties without clear ownership, and (partially) absorb residual uncertainties.

This work culminates in several recommendations. To summarise, it is recommended to:

1) Call for directing progress in uncertainty management: organise relevant stakeholders at value chain level to distribute their uncertainties collaboratively and develop policy concepts that trigger such collaborations.

2) Build of a shared view on risk/uncertainty and mitigation strategies: Value Network Maps and their subsequent Analysis could facilitate this process. The mature risk management discipline offers limited guidance.

3) Focus first on low hanging fruit: Apply (1) and (2) first on the easiest to realise value chains to build hands-on experience with addressing uncertainties collaboratively by means of the 5-step approach that is proposed.

Appendices

Appendix A) Methodology of the study & workshop details

Chapter 2 describes the identification and ranking of uncertainties, based upon this information recommendations are distilled as to how to manage these uncertainties.

Throughout this process four core principles of risk management[7] were embraced:

1. <u>Create value</u>: The uncertainty assessment is conducted with the aim to contribute to societal goals which requires a multidisciplinary view throughout the assessment.
2. <u>Focus on decision-making</u>: Outcomes are envisioned to be of relevance to decision-makers at private (corporate) strategic level
3. <u>Tailored</u>: The assessment process is adapted to the hydrogen value chain context by means of a workshop approach.
4. <u>Dynamic, iterative and responsive to change:</u> The presence and acknowledgement of uncertainties changes constantly. The process aimed to accommodate to include continuously evolving views on uncertainty.

Central in the process was a workshop that was designed to identify and rank uncertainties. About 40 participants joined from the hydrogen ecosystem. The collectively agreed, most pressing uncertainties legitimated the need for the development of action plans.

The overall process was as followed:

1. Selection process of critical stakeholders, see Table 3 for participants in the workshop.
2. With these stakeholders share, discuss and agree key uncertainties during the workshop (held on 8 Feb 2023)
3. Reflect on workshop output through a separate virtual meeting (held on 8 Mar 2023)
4. Further reflect/process the output of the workshop (e.g., validate & interpret)
5. Report to HyDelta consortium and disseminate outcomes.

The workshop itself was designed around several break-out sessions in which subgroups were asked to have conversations and answer pre-formulated questions. The agenda was structured as follows:

1. Plenary scene setting and objectives
2. Break-out session: identification of uncertainties
3. Break out session: prioritization of uncertainties
4. Plenary session: shared view on prioritized uncertainties
5. Break-out session: initial set of actions for the top 5 prioritized uncertainties
6. Feed-back from participants

[7] https://www.iso.org/iso-31000-risk-management.html

The interpretation and synthesis of the outcomes collected over the course of the workshop were executed during a two-step process:

1. Verification step of the uncertainties
2. Explore solution space (value networks and collaboration methodologies) how to manage the most pressing uncertainties

Both the raw inputs gathered and synthesized outcomes are available to the reader in the appendices B and C of this document.

In order to bring to the workshop a variety of perspectives and expertise's, seven groups of stakeholders were identified. The aim was to have at least one representative of each stakeholder group participating in the workshop. The list of the stakeholder groups, contributing organisations and number of participants is shown in Table 3.

Table 3 Stakeholder type representation list for the workshop held on February 8th

Stakeholder type	**Contributing organisations**	**Participants**
(semi-)government / Ports	ACM; EZK; TKI New Gas; Port of Rotterdam; Port of Amsterdam	5
Finance / Investor	InvestNL; a.s.r; SHIFT invest; ABN Amro	5
H_2 Production	Lhyfe, AirProducts	2
H_2 Transport / Storage	Gasunie; Liander; Stedin; NetbeheerNederland; EBN;	13
H_2 Demand	Yara; Tata Steel; Wienerberger Ceramics;	3
OEM / Service / Consultancy	NedStack; PwC; McDermott; Van Oord; DNV	7
Research Institute	TNO; New Energy Coalition	5

Appendix B) Uncertainty identification

Section 2.2 provided uncertainty related conclusions from deliverable 2.2. The underlying events identified in Deliverable 3.2 are listed below. These events were included in the overall prioritization process. For the sake of completeness, the Deliverable 3.2 events are listed below.

1. Outperformed by competitor/competing technology
2. Insufficiency of installed technological capacity
3. Misalignment in timing of installed capacity
4. (Non)renewable regulatory status of Dutch Hydrogen
5. Under or over utilisation/performance of asset
6. Presence of liquid / open hydrogen market
7. Safety issues with hydrogen technology

Uncertainties identified at the stakeholder workshop can be found in the table below, grouped in a range of categories. All in all, some 156 uncertainties were identified (including overlaps).

Outcome of uncertainty identification step based on input from 40 hydrogen ecosystem representatives (1/4):

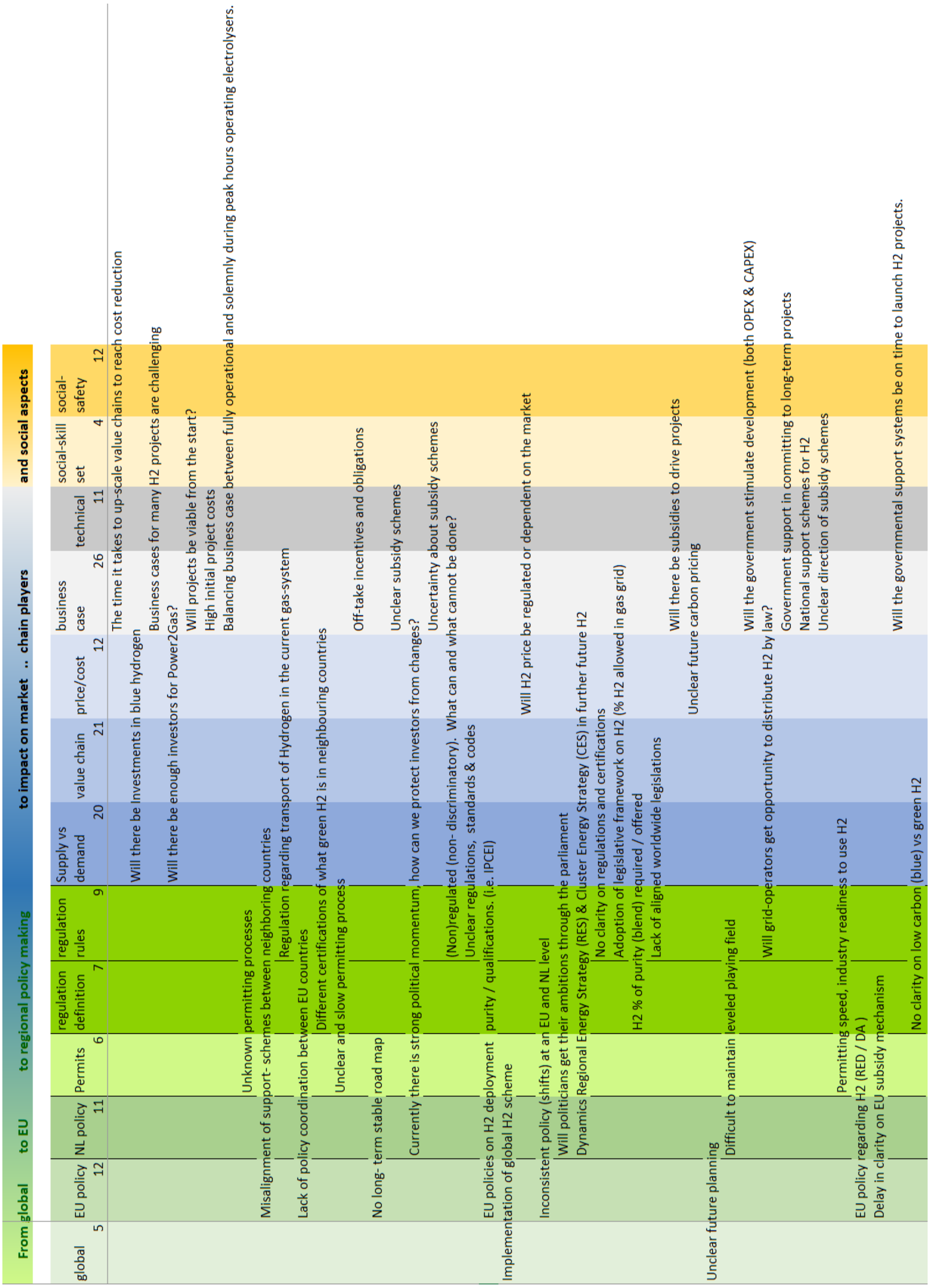


Figure 15 Workshop outcome uncertainty identification (1/4)

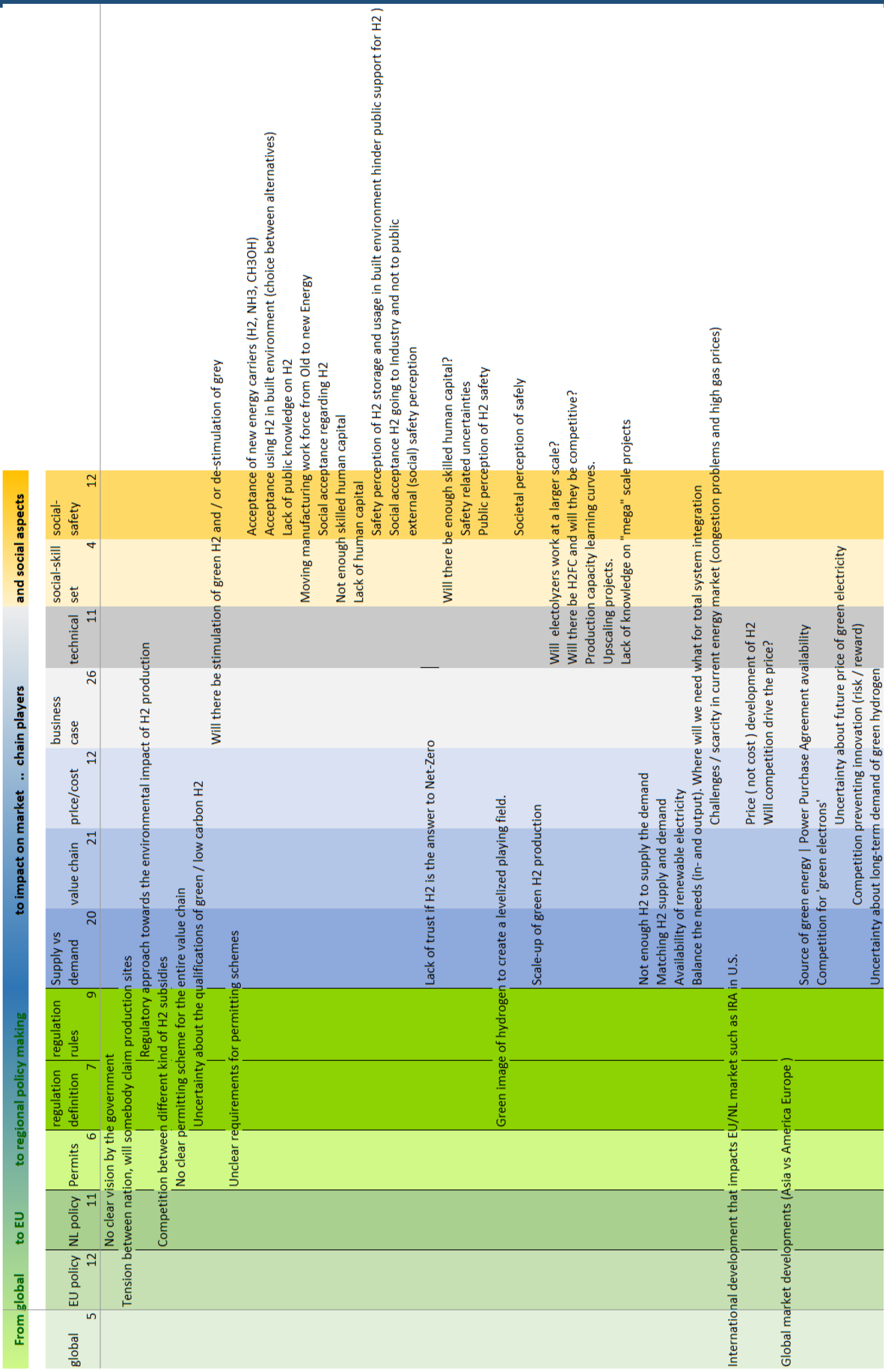


Figure 16 Workshop outcome uncertainty identification (2/4)

Figure 17 Workshop outcome uncertainty identification (3/4)

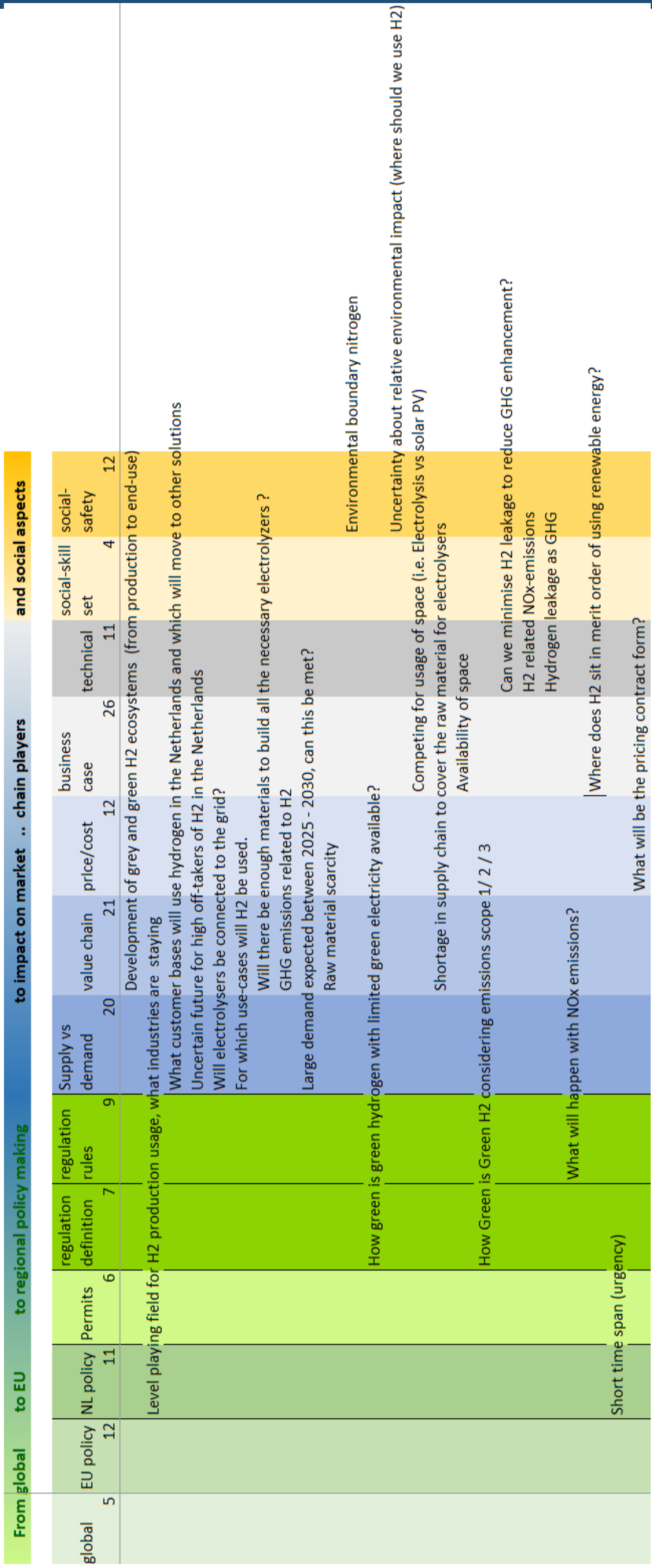


Figure 18 Workshop outcome uncertainty identification (4/4)

Appendix C) Uncertainty prioritization

The grouped uncertainties and underlying individual uncertainties are presented below. It is important to note that not all 156 uncertainties are included in the uncertainty prioritization step. Some uncertainties were disregarded as they did not meet the prioritization threshold and some uncertainties that did fell under the prioritization are not included here to guarantee the readability and structure of the appendix.

Level playing field for H_2 production usage, what industries are staying in NL/EU-

- Difficult to maintain competitive position with regard to level playing field
- Chemical industry (bulk demand) leaves EU and starts to operate in USA, middle east etc.
- Uncertain future for high off takers of H_2 in the Netherlands

Unpredictable volatility and trends on global energy/carbon market

- Unclear future carbon pricing
- Will there be investments in additional blue hydrogen projects
- Scarcity in current energy market (high gas/coal/power prices)

Social acceptance H_2

- Societal perception of safely
- Social acceptance H_2 going to Industry and not to public - fairness principle
- External (social) safety perception
- Acceptance using H_2 in built environment (choice between alternatives)
- Acceptance of new energy carriers (H_2, NH_3, CH_3OH)

Long term partnerships may not be successful

- Commitment of large industrial players

Will there be multiple gas infra systems? NatGas vs H_2

- Regulation regarding transport of Hydrogen in the current gas-system
- Will there be 2 gas connections temporarily (H_2 and NG), or a full switch at some point?

Conflicting message w.r.t. environmental impact H_2: emission impact of H_2 leakage

- Environmental boundary nitrogen
- Renewable image of hydrogen to create a levelized playing field.

Maintain strong political momentum

- Currently there is strong political momentum, how can we protect investors from changes?

Flaws in synchronized scale-up of green H_2 production and raw material scarcity

- Will there be enough materials to build all the necessary electrolysers?
- Raw material scarcity
- Shortage in supply chain to cover the raw material for electrolysers

Competition between different kinds of H_2 subsidy schemes (USA/EU/..)

- Tension between nation, will somebody claim production capacity offtake
- Misalignment of support- schemes between neighbouring countries
- Lack of aligned worldwide legislations

Future price of hydrogen carrier imports

- Risks of financing when production happens in other countries
- Bulk ammonia imports from the middle east instead of own production

H_2 Demand remains very limited

- Absence of H_2 off-take incentives and obligations
- Unclear future H_2 cost price
- H_2 too expensive compared to alternatives

Balance the needs (in- and output). Where will we need what for total system integration

- Who has the flexibility to take up the intermittency of H_2 production: reliable H_2 in Dutch energy system
- Need for hydrogen storage
- Balancing business case between fully operational or peak hour operating electrolysers.

What H_2 carrier import infrastructure will be accommodated

- Acceptance of new energy carriers (H_2, NH_3, CH_3OH)

Not enough skilled human capital

- Moving manufacturing work force from Old to new Energy
- Loosing knowledge in the EU (=NL) to remain competitive

Power play amongst energy companies

- Multiple countries (NL + DE + UK + DK + ...) all want to be leading in H_2

Unclear and slow permitting process

- Unclear requirements for permitting schemes
- No clear permitting schemes for the whole value chain

No clarity on low carbon (blue) vs green H_2 definitions

- Uncertainty about the qualifications of green / low carbon H_2
- Unclear regulations, standards & codes
- Different certifications of what green H_2 is in neighbouring countries
- Will there be investments in blue hydrogen

Inconsistent and shifting policy at NL level

- Competition holding up innovation (risk / reward)

Uncertainties in the renewable electricity supply reliability

- How green is green hydrogen with limited green electricity available?
- Where does H2 sit in merit order of using renewable energy?
- Unclear availability of cheap wind offshore
- Competition for 'green electrons'

No long- term vision with stable road map NL

- No clear vision by the government
- Complex ecosystem, no central direction / leadership
- Will politicians get their ambitions through the parliament
- Incomplete vision on the energy system
- Government support in committing to long-term projects

Will electrolysers operate effectively at a larger scale?

- How will electrolysers work at a larger scale
- Lack of knowledge on "mega" scale projects

Scarcity in energy transport capacity

- How many onshore electrolysers will be built?
- Will electrolysers be connected to the grid?
- No clarity on the timely availability
- y of infrastructure
- Availability of space
- Can electrolysers be connected to the grid (technically & spatial)
- Competing for usage of space NL (e.g., electrolysis vs solar PV, trace infrastructure)

Will grid-operators get opportunity to distribute H_2 by law?

- Regulation regarding transport of Hydrogen in the current gas-system

Where do investments take place? At production or demand side? NL or foreign country?

- Up-front long-term investment + customer commitment

Inconsistent and shifting policy at an EU level

- Lack of policy coordination between EU countries
- EU policies on H_2 deployment purity / qualifications. (e.g., IPCEI)

The time it takes to up-scale value chain technology to reach CAPEX cost reduction

- High initial project costs - how fast does e.g., electrolyser capex decline & to what level?
- Production capacity learning curves.

Uncertainty about subsidy schemes

- Will there be subsidies to drive projects
- Delay in clarity on EU subsidy mechanism

Appendix D) Comparison of different stakeholder analysis methods

Stakeholder analyses are often used to identify, understand and assess the needs, dependencies and interests of various stakeholders that might be affected by a decision. Stakeholder analyses are widely used in project management, strategy planning and risk assessment (Brugha & Varvasovszky, 2000). In this study the need to better understand the different interdependencies within the hydrogen value chain was an evident precondition to analyse what the effect on those interdependencies will be in the case of an uncertain event. To select a suitable stakeholder analysis method a short-list of stakeholder analysis methods was made and one method was chosen:

MACTOR analysis: The first method that was considered is called the MACTOR (Matrix of Alliances and Conflicts: Tactics, Objectives, Recommendations) analysis. This tool is used identify and analyse the alliances (same interest) and conflicts (contradicting interests) amongst different stakeholders in a value chain. This is done through comparing the objectives, interests' convergence and divergence against each other. The tool is often used by project managers to identify the stakeholders that could form an alliance in the project as well as managing all the potential conflicts. A MACTOR analysis will give the decision-maker insights in possible coalitions, appropriate strategies for each stakeholder and a clear visualisation of expected and unexpected aspects in the ecosystem (Godet, 1991).

Q-methodology: A Q-methodology is a qualitative approach used to identify different perspectives amongst stakeholders. When applying the method, relevant statements are identified and ranked by different stakeholders (participants) according to their level of agree- of disagreement. The results of this process can be analysed to understand the different interests and concerns of the stakeholders and develop a strategy accordingly (Cuppen, Breukers, Hisschemöller, & Bergsma, 2010).

RACI matrix: The RACI (Responsible, Accountable, Consulted, Informed) matrix is a tool used to define the responsibilities of different stakeholders in a project, value chain or ecosystem. All stakeholders have different roles, and this matrix aims to identify which stakeholders are responsible or accountable for a certain task and which stakeholders need to be consulted or informed before and during the tasks. The RACI matrix is valuable to analyse who does what in the ecosystem to fulfil certain value propositions, it does not depict the interdependencies of these tasks (Suhanda & Pratami, 2021).

Value network analysis: A value network is a map of nodes and connections containing all relevant stakeholder roles and the transactions of value between the different roles. Value can take many forms: payments, products, services, information, data, influence and contractual agreements amongst other things and can thus be tangible or intangible. Creating a value network is a valuable tool to visualise the different key stakeholders and their interdependencies, complex relationships and roles within an ecosystem (Allee V. , 2008).

Each of these methods have their own strengths and weaknesses, which makes them suitable for different purposes. Within this study the value network analysis method is chosen because it is considered the best tool to clearly depict the interdependencies within an ecosystem and the effect of uncertainties thereon. The value networks were created using two online tools: [CANVA](www.canva.com) (www.canva.com) and [KUMU (www.kumu.io)](www.kumu.io).

Appendix E) Uncertainties in an ammonia value chain

As explained in Chapter 3 uncertainties have a cascading effect within an interconnected value chain. The more complex and interdependent a value network, the more havoc can be caused by knock-on effects of uncertainties. To better visualise the complexity of the hydrogen value network a very general overview of a VNM of the hydrogen value chain is shown in Figure 19.

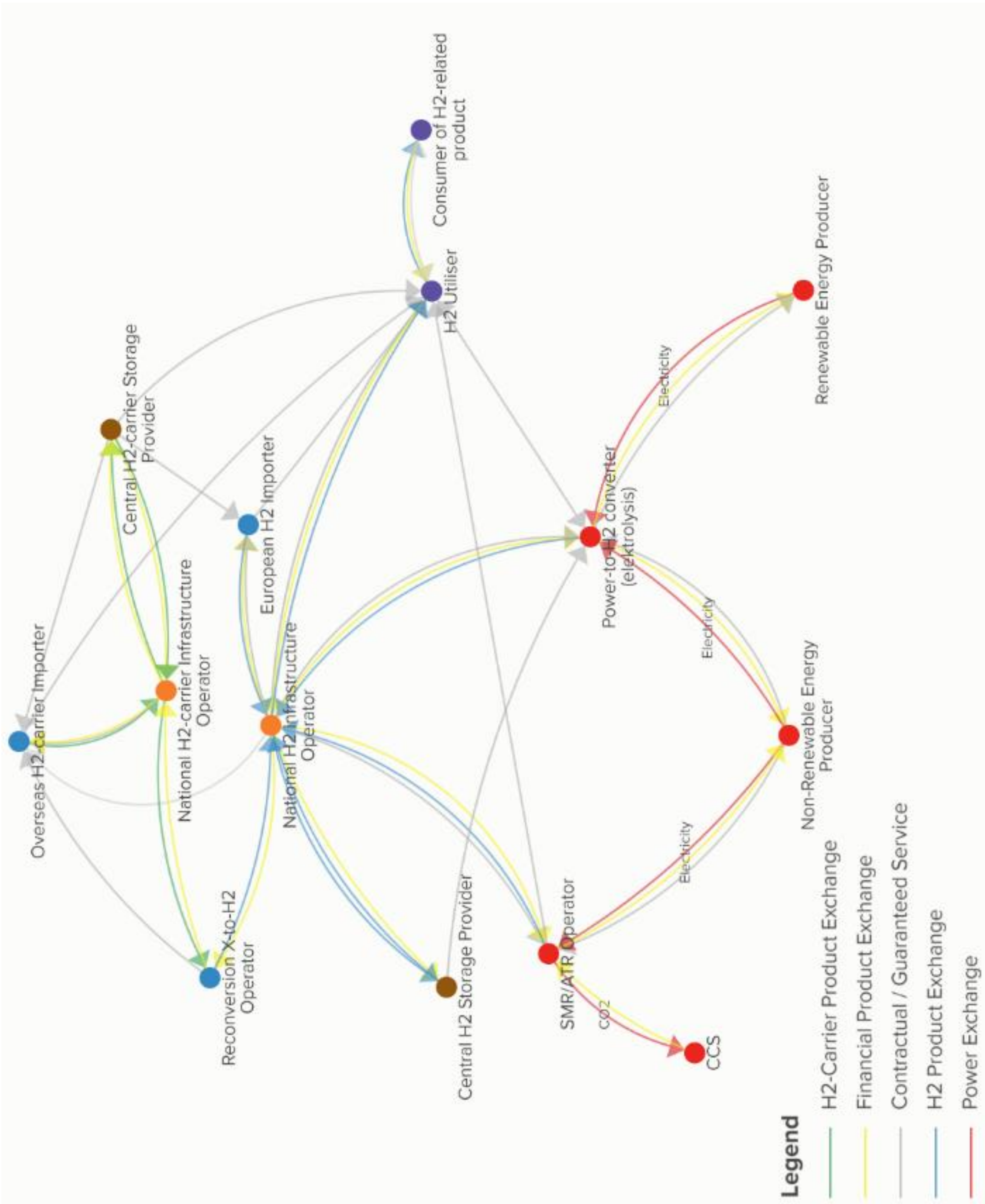


Figure 19 General overview of the hydrogen value chain in the Netherlands

The multitude of (interconnected) lines drawn between each node indicate the level of complexity. Each node depicts a central stakeholder group but in reality, there are also a multitude of stakeholders that operate within that node, further increasing complexity. For example, there is not a single renewable energy producer or renewable energy production method.

To test the relation between complexity and cascading effect of uncertainties a more in-depth, a VNM was created, depicting the bulk import of ammonia to the Netherlands [Figure 20].

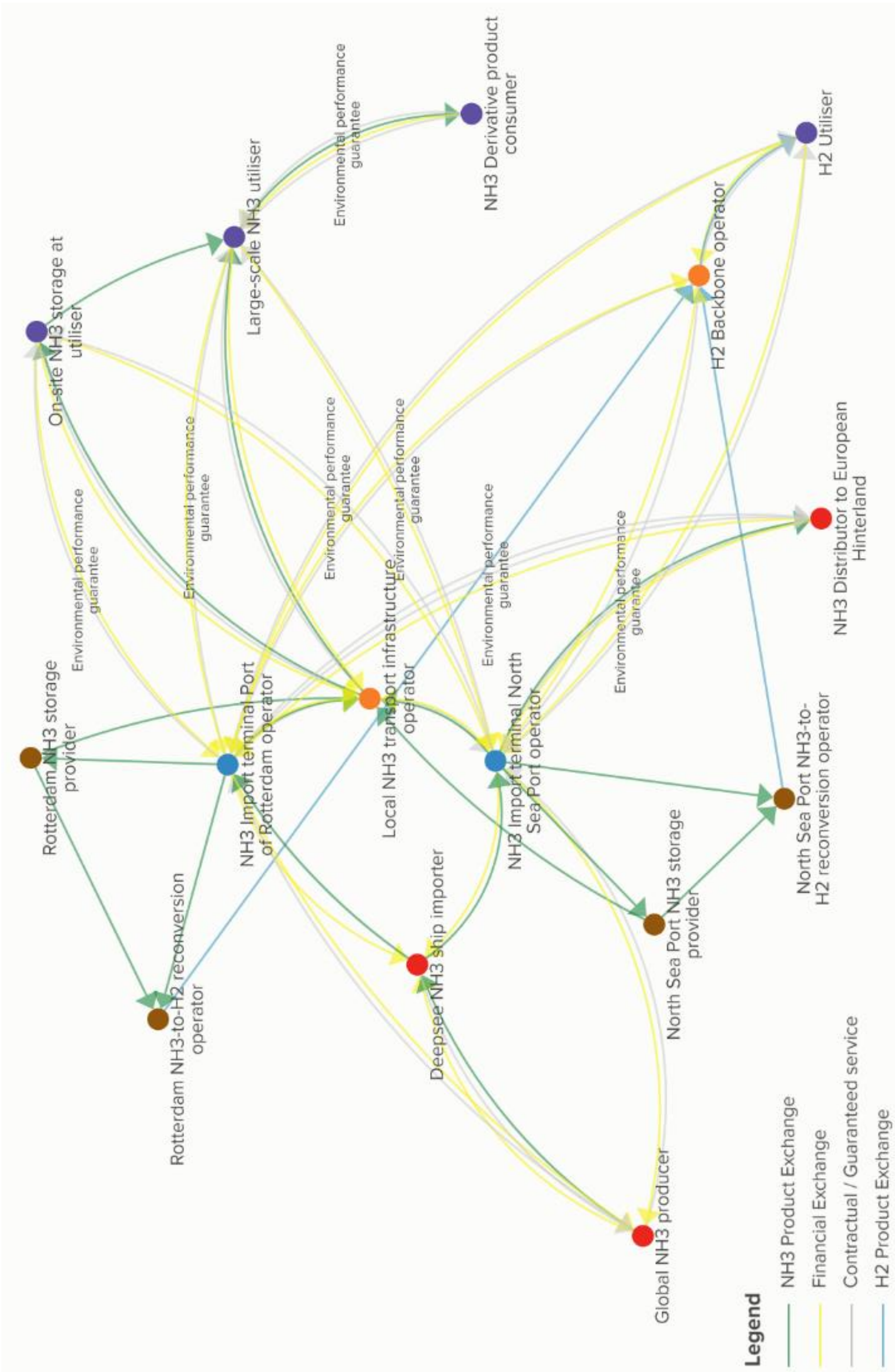


Figure 20 VNM for the expected value chain of bulk NH_3 import in the Netherlands

Two harbours were selected that could play dominant role in the import of ammonia: The Port of Rotterdam and the North Sea Port. Note that the contractual / guaranteed services in figure XX describe either offtake agreements or a guaranteed storage / transportation service.

For example, uncertainty related to social acceptance of an ammonia import terminal infrastructure will translate to uncertainty related to import scale-up potential. Clearly this hinders investment decisions in such a port ecosystem. This is detailed further in Figure 21.

Assume that lack of social acceptance reduces ammonia import by the Port of Rotterdam – which currently imports 400ktpa of ammonia[8]. This first order effect, labelled as [1] in the figure, then causes multiple second order effects [2]: No NH_3-to-H_2 reconversion and less NH_3 distribution to the European Hinterland. The next order effects [3] are the loss of H_2 converted from NH_3 to the H_2 backbone and the reduction of NH_3 utilisation in the European Hinterland. The avalanche of connected uncertainties continues further in a multitude of other exchanges, like new value transactions between stakeholders and other stakeholders that fall outside of the scope of this VNM.

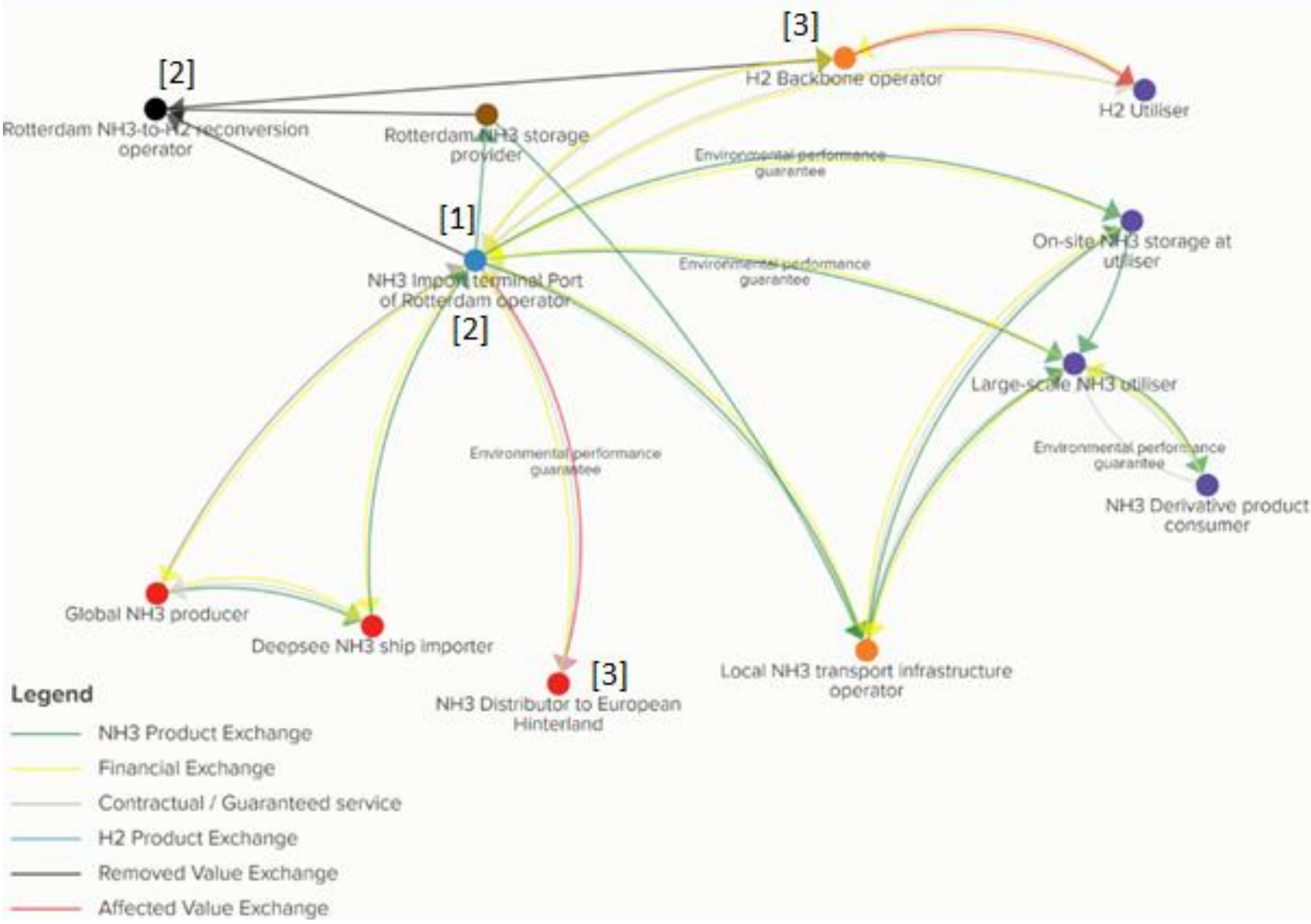


Figure 21 Cascading uncertainty within the VNM of figure 20

As the effects are felt by many stakeholders, the mitigation of social acceptance uncertainties should incorporate collaborations of all stakeholders that are directly and indirectly affected by potential consequences. An instrument to (re)-distribute investment risks and uncertainties amongst multiple stakeholders is proposed in Chapter 3 (five step proposal). It is recommended to keep the value chains as small as possible and the CANVA tool in chapter 3 can be of help.

[8] See: https://www.rotterdammaritimecapital.com/insight/oci-expands-import-terminal-for-green-ammonia

Appendix F) Investment risks in distribution networks

HyDelta 2.0 deliverable 3.2 has presented an overview of risks that were identified in a previous series of workshops, and a quantification of the effects (but not the probabilities) of some of these. This took the form of a what-if analysis, where abstractions of risk events were simulated in energy systems models to get a sense for their quantitative impact. We will not repeat the entire analysis here, but briefly touch on some of the main conclusions, with a focus on infrastructure, such that the link with the qualitative analysis becomes clearer.

Risks considered:
The risks considered in the quantitative analysis included:

- (In)sufficiency of installed technological capacity or (mis)alignment in timing of installed capacity
- (Non)renewable regulatory status of Dutch Hydrogen, through the proxy of a varying CO_2 price which creates a cost difference between green and grey hydrogen.
- Presence of liquid / open hydrogen market, through the proxy of (un)availability of sufficient infrastructure for trade, including import/export infrastructures.

These risks were selected for quantitative analysis because they were identified as important by the stakeholders in our workshops, and because they could be modelled in the energy systems models that are typically used for techno-economic analysis of energy systems. These models include representations of the physical networks, including the physical laws that govern them (e.g., balance of flows at each location). They also include representations of hydrogen markets. These are usually highly simplified, partly because the scale and complexity of an energy system model prevents highly detailed representations of any single part, but also because there is so much uncertainty about the detailed objectives of individual market participants, and the design of future markets, that more detailed assumptions would be arbitrary or impossible to validate. Still, it is possible to abstract some conclusions.

For instance, model results for **hydrogen storage** show that in the simulated combined Dutch gas-hydrogen-electricity system of 2030, hydrogen storage plays not only a limited role for hour-to-hour arbitrage but is also more susceptible to certain types of risk, including the risk of lower than planned electrolysis capacity, than other parts of the supply chain. This happens because the benefits of storage for arbitrage are not a function of price levels themselves, but of differences in prices between time periods. The same is true for **import/export facilities**, such as import terminals; their benefits depend on price differences between locally produced and externally procured hydrogen, which also makes them more susceptible to risk. Model results also showed that hydrogen risks do not yet easily spill over into (transmission-level) **electricity systems** in 2030, as the main link between the two systems (electrolysis) is still relatively small and most active during periods when electricity prices are already high.

Adding uncertainty:
The analysis of (quantitative) risks in D3.2 and (qualitative) uncertainties outlined above need to be seen in combination to derive the most meaningful results, as we will attempt in the following chapters. This is important, because:

1) Any quantitative analysis of the future is based on restrictive assumptions and subjective assessments of parameters. The exact numbers resulting from a model-based simulation of the future should therefore not be taken literally in any case. They can provide insight into mechanisms that would not have been thought of in a qualitative analysis, and often also

give order-of-magnitude quantitative assessments. Combination with qualitative analysis can help map the restrictions of quantitative models and model outcomes and put them in a broader context.

2) Factors that cannot be quantified are not less important that factors that can be. It is often tempting to base decisions mostly on quantitative factors, because these are perceived to be less subjective, and give not just direction but also a magnitude of the impact of a decision. This does not lead to the best decisions. Factors that models can easily quantify are also often the factors that are already better understood, and that have a smaller impact than factors that cannot yet be quantified.

The rest of this deliverable will therefore focus on the qualitative uncertainties, but with the quantitative results present in the background.

Risks in distribution networks:
In the above analysis, we have focused especially on risks and uncertainties at the national level, i.e., in transmission and distribution networks. In distribution networks, many risks and uncertainties are similar, but some are larger. In order to also understand the investment risks in hydrogen distribution grids, this section briefly describes the relevant differences between distribution and transmission grids. An indication is given of the cost characteristics of converting the distribution grid, and the foreseen phases during the conversion and operation of hydrogen distribution grids are described including the most relevant potential events that could influence the costs during the conversion phase. The information was retrieved via interviews with HyDelta WP7 project team members, and the existing literature.

Differences in converting the distribution and transmission grid:
Two differences in characteristics of the gas distribution grid compared to the transmission grid should be taken into account:

- The gas transmission grid has parallel pipelines over a large share of the trajectory. This means that just one pipeline can be converted in the initial stage and customers have the option whether to keep their natural gas connection or not. The distribution grid involves usually single pipeline sections, which means that if the existing grid is reused for hydrogen, all customers of that part of the grid must convert their connection or disconnect from the gas grid.
- The gas distribution grid has a significantly larger number of connected customers than the transmission grid. Moreover, the distribution grid enters citizens homes and crosses crowded locations such as city centres with a lot of public activity.

General cost characteristics of converting distribution grids:
There are not many existing public publications on the costs of converting gas distribution grids in the Netherlands towards hydrogen. Most of the studies on this topic (Weeda & Niessink, 2020), (Hoogervorst, 2020), (KIWA & Stedin, 2019), (Jongsma, Veen, & Vendrik, 2020) refer to a study that KIWA performed in 2018 (Kiwa, 2018) in order to investigate the conversion costs in the different ‘Net van de Toekomst’ energy scenarios (CE Delft, 2017). One newer cost study is available that considers the investigations done for Waterstofwijk Hoogeveen (Hazenberg, 2020).

Table 4 Overview total conversion and annual operation costs of the Dutch distribution grid towards hydrogen under different future energy scenario's (Kiwa, 2018)

Scenario	Regional	National	International	Generic
% of housing-equivalents[9] converted to H_2	3% ($0.3\ MW_{eq}$)	37% ($3.3\ MW_{eq}$)	29% ($2.6\ Mw_{eq}$)	0%
Conversion costs (M€)	59	678	527	0
Annual costs (M€/y)	36	422	328	0

Table 4 shows that the investments for the conversion (e.g., the one-off costs) are relatively small compared to the annual costs to operate and inspect the grid. This is because most grid components are assumed to be suitable for repurposing the grid for hydrogen (Kiwa, 2018). Based on the numbers in Table 4, as a rule-of-thumb, it can be said that conversion of the grid costs 200 €/housing-equivalent or 13500 €/km (Weeda & Niessink, 2020). Grid components that are not suitable for hydrogen are typically the older components that are already planned to be replaced, even without conversion to hydrogen. Therefore, these do not contribute significantly to the conversion costs. One exception is that the customer's gas meter has to be replaced. Another physical cost component of consideration (although officially not part of the gas distribution grid) is the gas receiving station (GOS). In II3050 the costs for a new, or repurposed GOS for hydrogen were estimated to be one million Euros (Netbeheer Nederland, 2021). In the Netherlands there are approximately 750 GOS that deliver natural gas from the transmission grid to the distribution grids.

Since, in addition to the gas meter and GOS, labour costs are expected to contribute for a large share to the conversion costs, it is relevant to understand the conversion process in greater detail and the unexpected events which could delay or cause additional work during the conversion process.

Overview phases converting distribution grids towards hydrogen:
Figure 22 provides an overview of the phases during conversion and operation of the hydrogen distribution grid. Under our scope[10] the conversion process starts when the municipality has decided in the 'Transitievisie Warmte' that a specific region should be converted to hydrogen. After this decision, it is expected that it can take multiple years before the converted hydrogen grid is operational. In this section we will describe each phase shortly and include the major risk events relevant for earning back potential investments.

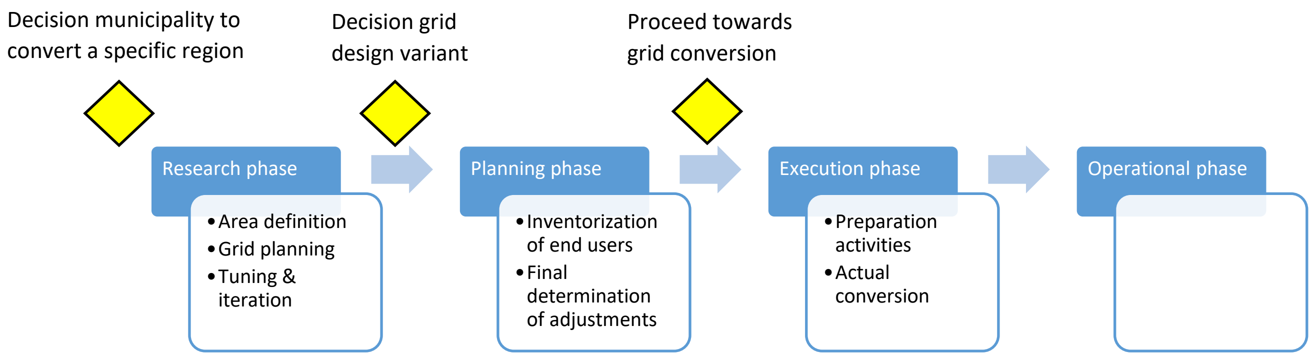


Figure 22 Overview phases converting distribution grids towards hydrogen

[9] Dutch: 'woningequivalent' (WEQ)
[10] Similar to HyDelta WP7

Research phase:
After the municipality has decided that in a specific region the natural gas grid should be converted, the distribution system operator (DSO) will investigate different design variants of how the distribution grid can be converted. Examples of differences between the investigated variants could be the location of the (new) gas receiving station (GOS)[11] , the exact parts of the grid that will be converted, etc. After this phase there is a clear initial picture of how the grid can be converted.

Table 5 Potential events and impact during the phase: investigation of grid variants

Potential events	Likelihood	Impact
Municipality decides to stop the conversion process	Unlikely	Unclear if the DSO expenses for the investigations will be compensated or not
No permission received for proposed GOS location	Unknown	Find another location

Planning phase
In this phase the stakeholders connected to the part of the existing distribution grid under consideration will be more actively informed and asked for information about their relevant characteristics. A database will be filled with inputs from these customers to get an overview of the area. During this phase a first insight is gained in how many customers are willing to convert, and what share of customers is considering to sever their connection to the gas distribution grid. It is foreseen that part of the customers will not respond or leave input at all. Until their response, it will normally be assumed that these customers are not willing to get a connection to the hydrogen grid. Note that the decision of the customer (and satisfaction afterwards) to a great extent depends on the propositions delivered by the energy suppliers and installation companies, which are out of influence of the DSO. After this phase the final decision is taken to move towards conversion of the grid.

Table 6 Potential events and impact during the phase: investigation of connected stakeholders

Potential events	Likelihood	Impact
A large share of customers is not willing to be converted to hydrogen	Unknown	Lower expected revenues for DSO (connection tariffs). Potentially connection tariffs have to be increased.
Public opposition starts because customers are confronted with the actual impact of the conversion	Unknown	Unknown: could include delays, legal proceedings, etc.

Execution phase – preparation activities":
The conversion of the distribution grid towards hydrogen means that customers are temporarily disconnected from the gas grid. Therefore, it is essential to carefully prepare and plan this phase and mitigate uncertainties as much as possible. It is a big coordination issue; the impact can be big if issues arise during the period that customers are disconnected. Therefore, as much as possible is done before the actual conversion starts. This includes, among others:

[11] Which is called a 'Hydrogen Delivery Station' (HDS) by Hydrogen Network Services

- Installation of an H_2 ready boiler and metering equipment in the houses, plus alternative required systems (e.g., electric cooking).
- Planning eventual replacements of gas pipeline parts together with other activities in the ground.
- Making sure that enough well-skilled technicians are available during the actual conversion phase (as well-skilled technicians are scarce, it will not be possible to convert all regions in parallel during one summer. It is expected that a long-term planning is required to coordinate the sequence of the converted regions).

In all these actions a large number of different stakeholders are involved (installation companies, municipalities, DSOs, customers, other (indirectly) impacted stakeholders, etc.). There are a lot of responsibilities divided over these stakeholders, HyDelta WP7 is compiling a RACI-matrix[12] but for a lot of responsibilities it is still unclear which party needs or wants to take the responsibility.

Table 7 Potential events and impact during the phase: preparation of conversion

Potential events	Likelihood	Impact
Coordination and planning issues (delivery equipment, installation issues, cooperation of customers, alignment other activities in the public area, etc.)	Likely	Delays, additional labour costs
Unavailability of materials and components (e.g. H_2 ready meters, boilers, etc.)	Unknown	Delays, additional labour costs

Execution phase - Actual conversion:

In principle, almost everything should be ready before the actual conversion phase starts. What still needs to be done is to disconnect the natural gas supply in this part of the grid, to flush the pipelines and to switch the grid connection in the houses from the old boiler to the already newly installed H_2 ready boiler. The current idea is to convert the grid in sections of 500 connections per five working days. This requires that 50 technicians are available, each of whom can convert two connections per day. Sequentially, the distribution pipes in the area are flushed. The actual conversion is normally only performed in summertime because households will be disconnected from the grid for around a week. For commercial customers that use gas for specific processes, specific arrangements are made upfront.

Table 8 Potential events and impact during the phase: actual conversion

Potential events	Likelihood	Impact
Customers, although very well informed, are not home and cannot let in technicians during the actual conversions.	Likely (that this will occur over a very large group)	Unknown as of yet: for the conversion process it would be beneficial if these customers can be skipped and converted at a later time. For the customer this would mean that they are disconnected for a longer period.
Despite preparation and mitigation measures, there is still a delay in the actual conversion.	Unlikely	Customers are disconnected for a longer period, reputational damage, eventually financial compensations, technical labour occupied for a longer period

[12] A RACI matrix maps roles: who is Responsible, Accountable, Consulted, or Informed?

Accidental (safety related) issues.	Unlikely	Unknown, large reputational damage, public opposition, customers change their minds

Operational phase:
During the operational phase of the distribution hydrogen grid the considered investment risks are similar to those in the transmission grid. For example, customers can still choose electrification after conversion of their gas connection to hydrogen. Similarly, they can choose to insulate their buildings or install a hybrid heat pump to decrease their hydrogen usage. This can impact the earnings of the DSO while the operational costs to inspect and maintain the grid remain the same. The other way around, new customers can still register even if they previously indicated that they did not way to have a connection to the hydrogen grid. Therefore, planning methods may have to be more adaptable. However, this difference is similar to the transmission-distribution difference in the current situation with natural gas, and the foreseen H_2-ready boilers, measurement equipment and level of safety are not likely to differ very significantly compared to the current systems.

The major financial risks that are seen for converting the distribution grids towards hydrogen are related to two aspects. The first aspect is the high contribution of labour costs to the conversion process, which can be affected during the process due to several unexpected events. The expected duration of the conversion process and the required coordination between the different stakeholders increase the chance for delays, additional work and therefore the costs for the DSO to convert the grid. The second major aspect is the uncertainty to what degree customers do want, and keep the hydrogen grid connection over time, as there are a lot of stakeholders and potential events that can influence their decisions. The number of connections can strongly influence the connection tariffs customers will have to pay in the future (next to the other cost characteristics as the hydrogen price and the new appliances in relation to the alternatives).

Conclusions:
The insights from the quantitative risk analysis, combined with the qualitative uncertainty identification, give rise to a number of specific conclusions:

1. **Storage** is a key component of a future hydrogen system, but also a component that is unlikely to materialize in the required form unless additional action is taken. Quantitative modelling shows that, if we look exclusively of the value of storage for arbitrage, storage investment is risky and its business case shaky in the early stages of the development in a hydrogen system. The uncertainty analysis shows that the quantitative analysis considers only part of the uncertainty for storage owners and operators. Policy intervention and/or collaboration between market parties is clearly necessary. For example, in current gas markets, gas system operators book capacity to realise value from energy storage in providing system security, and charge all users of the system. A similar mechanism could provide a stable revenue stream for hydrogen storage. Since hydrogen storage at the national level usually requires large volumes, and use of underground, lead times are very long. In addition to a guaranteed revenue stream beyond 2030, policy action (including collaboration between local and national governments and infrastructure owners) can help ensure that investments are not postponed too long. This can, for instance, take the form of a clearly communicated shared roadmap for underground hydrogen storage development, explicit enough to also include locations, material/human resource/financial requirements and where they will come from, etc.
2. **Import infrastructures** (international pipelines, import terminals) are also risky investments, but simultaneously a mitigation strategy (against, for instance, high costs of locally produced

hydrogen). In comparison to storage, we are seeing more interest from private-sector investors. Here, there is a possibility that individual stakeholders, deciding under uncertainty, together build too much capacity. Since the amount of import infrastructure is an important feature of a national hydrogen system, coordination is necessary to make sure that we do not end up in a situation with a vast overcapacity.

3. Risks and uncertainties in **distribution networks** are, in many ways, similar to those at the national, transmission level. However, distribution networks have unique features which create a set of additional or larger risks. Investments in distribution networks generally have shorter lead times to those in transmission networks, so distribution network operators can, as long as they ready themselves for hydrogen, follow transmission investment rather than move ahead of it. However, if the use of hydrogen in distribution networks is an important part of a shared vision for the hydrogen system, it is important to already start thinking about collaboration and coordination mechanisms in distribution networks. Here, the parties that need to collaborate are often smaller, and there are often more of them. The coordination challenge in, for instance, converting part of a network from natural gas to hydrogen needs to be addressed sooner rather than later, even if the conversion itself will only take place much later.
4. There are now several coordination mechanisms for **electricity, gas and hydrogen transmission infrastructure** in The Netherlands. This includes the cluster energy strategies (CES), where industrial clusters come together to formulate plans and resulting infrastructure needs, the regional energy strategies (RES) and the provincial infrastructure plans (PMIEK), where provinces or regions make local plans together with stakeholders. These processes bring stakeholders together, which is good. The infrastructure projects, including those for hydrogen, that have been identified so far are consistent with national ambitions (Koelemeijer, van der Weijde, & Goossens, 2022), and reduce risk to market participants. However, they do not yet create a shared vision that can resolve the still remaining and still very large risk to, for instance, investors in electrolysis, storage, or hydrogen demand.

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