Framework for updating scenarios: A multi-layer framework for structurally incorporating new information and uncertainties into scenarios

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ABSTRACT

The dynamic and fast-changing environment brings challenges for generating long-term visions of the future; scenarios. Outdated scenarios will result in future pathways that are no longer achievable and therefore reduces their relevance and usefulness for making decisions. As some uncertainty is resolved over time, while other uncertainties arise, it is important to take these changes into account. Although the need to update scenarios to create meaningful insight for making decisions is clearly recognized, a clear and structured method for executing this process remains unclear. I propose that to configure a solution, two concepts need to be introduced 1) scenarios consist of a multi-layered structure, and 2) changes considered should be classified according to their impact and uncertainty. Based on this classification, changes are incorporated into the different layers distinguished. To apply these concepts during an update, the paper presents a generic framework to structurally incorporate new information and uncertainties into scenarios, keeping them up-to-date, guaranteeing that the scenarios remain realistic and useful. Within a test case the framework is applied to four scenarios describing the European power market to illustrate how the framework performs in a practical context. Hydrogen is chosen as an uncertainty, not yet considered in the scenarios, to illustrate how to structurally incorporate changes. Results show that using the framework allows the complexity of the update to be simplified into a step-by-step process. Additionally, it increases transparency by creating a common language for understanding *if* and *how* the changing external environment should be incorporated within scenarios.

1. Introduction

Climate change is increasingly gaining attention in almost all sections of society. Over the last decade, society has become increasingly aware of the problems related to our changing climate, which has led to different reactions around the world. Nonetheless, a successful transition towards a low carbon future is challenging and not a clear path resulting in an environment characterized by uncertainty and complexity. Due to this uncertainty and complexity, well-grounded projections about the future are an essential foundation for today's policy and investment choices. Scenarios are considered to be a valuable tool for dealing with uncertainties and complexity in the future (Amer, Daim & Jetter, 2013; Chermack, Lynham, & Ruona, 2001). Scenarios do not try to predict the future nor are they a business plan. They are used to understand how the world might develop and help us to imagine what the consequences of decisions made now are for the future.

The dynamic and fast-changing environment (e.g. government policy and emission target announcements, reducing costs of renewables by technological improvements) brings challenges for generating long-term visions of the future, as these rapid changes influence the plausibility and relevance of the generated scenarios. Outdated scenarios will result in future pathways that are no longer achievable and therefore reduces their usefulness for making decisions. As some uncertainty is resolved over time, while other uncertainties arise, it is important to take these changes into account.

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It is very inefficient and time-consuming to make new scenarios every time something changes, therefore, finding an efficient and time-effective way to incorporate new information into scenarios, is a research theme to be analyzed. Incorporating new information and uncertainties into scenarios will be referred to as performing "an update".

The need to update scenarios to create meaningful insights for making decisions is clearly recognized within literature (IEA, 2014; Leggett et al., 1992; Van Vuuren & O'Neill, 2006; Van Vuuren et al., 2010). However, while several studies discuss how an update is performed, a methodological approach for executing this process remains unclear. Executing an update is a complex process due to the increasing complexity of scenarios. Performing an update in an unstructured manner, therefore, imposes multiple problems. First, the update becomes time-consuming as there is no standardized way of executing the process, leading to inefficiencies. Secondly, as the process is often completed by multiple people, an unstructured way of working imposes difficulty in communicating how and which changes are made. Lastly, the process may lack transparency, which makes it difficult to understand the consequences of incorporating new elements into scenarios for the rest of the scenarios.

This research explores a way to structurally incorporate new information and uncertainties into scenarios, keeping them up-to-date, guaranteeing that the scenarios remain realistic and useful. This article therefore proceeds as follows: Section 2 provides a literature study to understand how scenarios are currently kept up-to-date and why this is not satisfactory. Section 3 introduces two concepts, highlighted by the literature study, that are found important to configure a solution. Section 4 discusses the different steps that together form the proposed dynamic scenario framework. In Section 5 a test case is executed to illustrate how the framework should be applied within a practical context. This highlights the benefits of using such a framework, while at the same time uncovering any of its limitations. Section 6 elaborates on the main results. Section 7 offers a discussion, before providing conclusions and recommendations for further research (Section 8).

2. Literature study

A literature study was executed with the objective to clearly indicate the current state-of-art of keeping scenarios up-to-date. Despite the importance of keeping scenarios up-to-date, the search of literature revealed that few studies go into detail on how an update must be executed (Creutzig et al., 2017; IEA, 2014; Leggett et al., 1992; Van Vuuren & O'Neill, 2006; Van Vuuren et al., 2010).

Schoemaker (1991) states that forecasts require to be updated frequently, while scenarios provide a general view for a longer period of time. "An Explorer's Guide" published by Shell (2008), talks about reviewing generated scenarios over the period of a few years. They do not state how this should be done but highlight that over a period of time, if the assumptions on which the scenarios were generated have changed, new scenarios should be created. No suggestion is provided to take new information into account within the already generated scenarios.

The International Energy Agency (IEA), does recognize the need to incorporate new information into their generated scenarios as they publish their World Energy Outlook (WEO) on a yearly basis, updating their previous version (IEA, n.d.-a). The IEA differentiates between political changes as some scenarios only incorporate formally adopted policies to create a baseline picture: *"current policy scenario",* while the *"new policy scenario"* also incorporates policy proposals. The IEA (2014) discusses that to determine which policy proposals are included, case-by-case judgement is used. However, they offer no explanation for how this process is structured.

Van Vuuren et al. (2010) also clearly indicates the relevance of updating scenarios and has highlighted several points of attention when performing an update. One of the insights from the paper is that a relationship is indicated between the nature of a change and how they should be treated during an update. New information may simply require some parameters within the scenarios to be altered, while other information may challenge the *"original critical assumptions"* of the scenarios which require new scenarios to be generated. The difference is related to the speed of change regarding these variables. It is argued to evaluate the long-term assumptions in these scenarios using appropriate long-term trends and should, therefore, not be influenced by short-term observations. This indicates the importance of differentiating between the changes in the external environment and how they impact the scenarios. Some small short-term changes might influence some components within the scenario while new long-term trends might question the relevance of the entire scenarios. However, besides indicating the relevance for evaluating scenarios and addressing ways to accurately do so, how to perform an update using the insights created is not described.

Creutzig et al. (2017) also critically examine the validity of scenarios using new information. Creutzig et al. (2017) thereby identify that the potential of solar energy has been systematically underestimated within energy scenarios. Indicating the underestimated growth of solar energy provides insight for updating this factor, however, changing this factor might also influence other components of the scenarios as they are highly interlinked. A weakness within this paper is that limited attention is being paid to the possible consequences of considering large changes to a single factor.

One of the most extensive descriptions of an update can be found in a paper by Leggett at al. (1992). In 1992, changing assumptions and new information that came available have led the IPCC to request for an update of their 1990 emission scenarios (Leggett et al., 1992). Leggett et al. (1992) discuss the performed update by highlighting how the assumptions, on which the 1990 scenario are built, have changed and new uncertainties have emerged. Taking these changes into account, six scenarios are presented. Two which represent a modification of the 1990 scenarios (IS92a and IS92b) and four scenarios considering new assumptions (IS92c-f). IS92a incorporates all new policies, affecting GHG emissions, agreed upon internationally and passed into national law. This scenario, therefore, only considers certain new information. IS92b includes also proposed GHG policies not yet agreed upon. The other scenarios explore other plausible assumptions not considered within the 1990 scenario. Leggett et al. (1992) extensively discuss what new information and assumptions are considered within the different scenarios, however, they make no attempt to address how these changes are assessed or why they are considered in a certain way. New uncertainties were translated into assumptions, but why some new uncertainties require a new scenario to be generated is unclear.

All studies reviewed suffer from the fact that no methodological process is found on how to incorporate new information and uncertainties into scenarios. However, to validate the claim that no method exists, some highly valued energy scenario experts were questioned for their knowledge of a specific method to structurally incorporating new information and uncertainties. Additionally, their expertise was used to provide input on improvements for the proposed framework. In total three experts were questioned: Prof. Dr. Detlef van Vuuren, Prof. Dr. Gert Jan Kramer and Dr. Oreane Edelenbosch. The most important insight from the conversations and also the main goal, was that none of the experts had read or heard of a method to structurally incorporate new information and uncertainties into scenarios.

From the literature study, three research gaps were indicated: 1) Van Vuuren et al. (2010) stress the importance of differentiating between parts within the scenario when performing an update. Small short-term changes might influence some components within the scenario while new long-term trends might require an entirely new scenario to be created. However, currently no distinction is made between layers within a scenario, 2) The literature clearly makes a distinction between changes and how they are considered within scenarios, however, fail to address how they execute this assessment. No tool is found to assess which changes need to be considered and why these are considered in a certain way, and 3) there is no structured process for determining how new information and uncertainties should be incorporated into scenarios.

3. Two concepts influencing how to update scenarios

Although the reviewed literature suggests that incorporating new information and uncertainties into scenarios can be a suitable mean to deal with the fast-changing environment, none of the reviewed literature goes into detail on how this process should be structurally executed. To configure a solution two important concepts are proposed 1) scenarios consist of a multi-layered structure, each layer having their own characteristics and 2) changes considered should be classified according to their impact and uncertainty, as the nature of the change will influence how the scenarios are affected. Based on this classification, changes can be incorporated into the different layers distinguished within scenarios.

As the ideas presented here are at the fundament of the framework proposed, it requires an introduction on how these ideas were generated.

3.1. Multi-layered scenarios

The existence of different layers within a scenario is implicitly indicated by the fact that an update can be performed by altering some parameters within the scenarios without changing the high-level storylines (Van Vuuren et al., 2010).

Additionally, this idea of a multi-layered structure is enhanced by the process of generating scenarios. Scenarios are built by formulating storylines that discuss possible futures while incorporating uncertainties (Bentham, 2014). Before these qualitative scenarios are used for strategic decisions, several steps are executed to quantify these storylines (Chermack et al., 2001; IPCC, 2005). The generation process of a qualitative scenario is about widening your scope and accepting that the external environment is changing, in our case qualitative in nature. Using these scenarios for strategic planning, on the other hand, is a process of making decisions on which areas to focus by increasing the amount of detail and reducing the level of uncertainty, and requires quantification. It is therefore concluded that within a scenario a more long-term macro perspective, qualitative in nature, and a more short-term focused (macro and micro) perspectives, quantitative in nature, is present.

As part of the solution, it is proposed to divide scenarios into four distinct layers: *Framework*, *Storylines*, *Industry specific fundamentals* and *Numbers*. To define the characteristics of these layers, this research uses a socio-technical approach to transitions as a source of inspiration; the Multi-Level Perspective (MLP). The MLP of Geels (2002) is recognized as a useful framework and makes a distinction between different layers in society to indicate how society develops over time. It thereby acknowledges that external changes influences society at different levels. Additionally, it highlights the interdependencies within and between the different layers.

The proposed layers are shown in figure 1. As dividing scenarios into layers is a novel idea; every layer is briefly discussed.

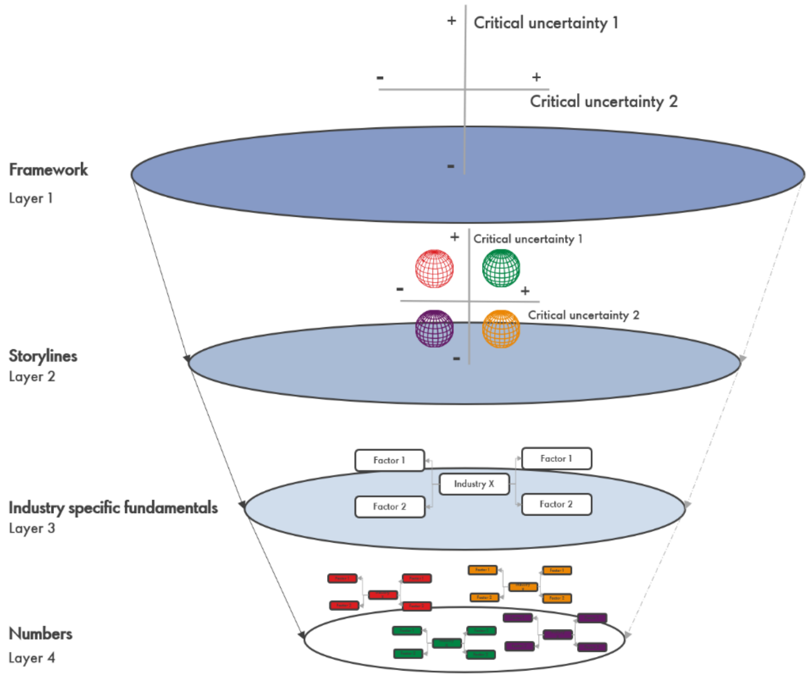

Figure 1: Multi-layered structure within scenarios

Important to note is that within each layer assumptions are formulated. As over time some uncertainty is resolved and new uncertainties emerge, it is important to examine the consistency of the assumptions with more recent data. Changes within the assumptions are an indication for an update. Proper indication of assumptions made in each layer is, therefore, essential to be able to update accordingly.

Layer 1 – Framework

The first layer, *Framework*, forms the basis on which the scenarios are constructed. This layer represents the critical uncertainties affecting the business and provides the context in which the rest of the layers are formulated. These critical uncertainties are developments or problems that are long-term, highly uncertain and have a high impact on the business environment (e.g. degree of decarbonization, generation mix in the future). Indicating the extremes of these uncertainties on a 2x2 matrix generates the *Framework* (figure 1), providing four different quadrants, which forms the basis for the qualified scenarios. The stable nature of this layer means it is not subjected to rapid changes and provides a long-term macro-perspective view. Moreover, as this is the top layer, it is outside of the direct influence of the lower layers. Changes to this layer would require entire new scenarios to be generated.

Layer 2 – Storylines

The second layer represents the *Storylines*, qualitative scenarios, generated using the *Framework* defined in layer one. This layer discusses multiple perspectives on how the world might evolve in a qualitative way. The resulting set of scenarios all represent the same critical uncertainties, however, within each scenario, this uncertainty unfolds differently (Cardoso & Emes, 2014). As these qualitative scenarios discuss the world's evolution from the present to the end state indicated, other uncertainties, besides the chosen critical uncertainties, are considered (Van Vuuren & O'Neill, 2006). This layer defines in more details how a world, in which these critical uncertainties play out differently, will look like. Thereby discussing the macro-perspective view of these future worlds and is, therefore, not subjected to fast changes. This layer is not directly influenced by the lower layers but is highly influenced by the top layer.

Layer 3 – Industry specific fundamentals

The third layer provides the building blocks for translating the qualitative scenario into a quantitative scenario. If we, quantitatively, want to indicate the future development of an industry, it is important to understand by which factors the industry is influenced. These often highly interdependent factors can be indicated by a flowchart showing the structure of this specific industry. The granularity of the flowchart is a trade-off between complexity and level of detail. This layer is subjected to relatively fast changes as new technologies, who gained some market share, will influence how this market is structured (e.g. electric vehicles). Additionally, the interdependency between the different factors within the industry is important. Changes within one factor might influence other components and should be kept in mind when scenarios are altered.

Layer 4 – Numbers

Within the fourth layer, *Numbers*, the qualitative scenarios are translated into quantitative scenarios using the *Industry specific fundamentals* indicated with layer three. External data is used to add numbers to the different factors indicated. For each individual scenario, these numbers should be altered based on the trends highlighted within this specific scenario. For example; a forecast of the percentage of electric vehicles in 2050 is 60%. In a scenario with high pressure for decarbonization, this percentage is thought to be 75%, while a scenario in which decarbonization is not a pressing topic this percentage could be 40%. It is especially important to indicate the sources of the data used for defining this layer as an update would require checking whether the numbers are still plausible and relevant. Recording these sources provides the opportunity to easily retrieve historical data, gather updated data from the same source and check if the decisions made are still valid.

Important to note is the interdependencies between the layers. Incorporating changes in higher layers would require changes in lower layers, while changing lower layers would not necessarily mean to change higher layers.

There are multiple advantages of defining this multi-layered structured within scenarios. At first, it provides a common language for what a scenario constitutes. By acknowledging the differences within a single scenario and explicitly stating the layers, it provides a tool for communication. Secondly, indicating the layers defines the current structure of the scenarios and provide a good overview to understand the relation between the different components. It thereby increases the transparency of what a scenario is and reduces some of the complexity of understanding these increasingly multifaceted scenarios. When incorporating changes, it will help to understand the consequences for the rest of the scenario. Appendix A presents a recap of the different layers discussed above.

3.2. Impact-uncertainty matrix linked to scenario levels

During an update, the nature of the change will influence how scenarios are affected. Currently, no tool exists for understanding which changes affect the scenarios in what way, even though literature indicates that it is crucial in trying to understand future situations (Benedict, 2017; Pillkahn, 2008). The most often used tool to classify changes as an input for generating scenarios, and therefore well-known, is an adapted version of the matrix of Wilson (1983) using two dimensions; impact and uncertainty (Pillkahn, 2008). The impact-uncertainty matrix is normally used to identify critical uncertainties, high impact and high uncertainty, around which the scenarios are built (Pillkahn, 2008). The impact refers to the current impact on the drivers of the organization or the current impact on the key factors of project success (Krueger, Casey, Donner, Kirsch, & Maack, 2001). The uncertainty is considered as: *"the level of variation in the range of possible evolutions of the driver itself"* (Speziale & Geneletti, 2014, p. 3).

Although the focus within this paper is on updating instead of generating scenarios, this research uses the impact and uncertainty level assigned to a change as a guideline to determine in which layer the change should be considered (figure 2).

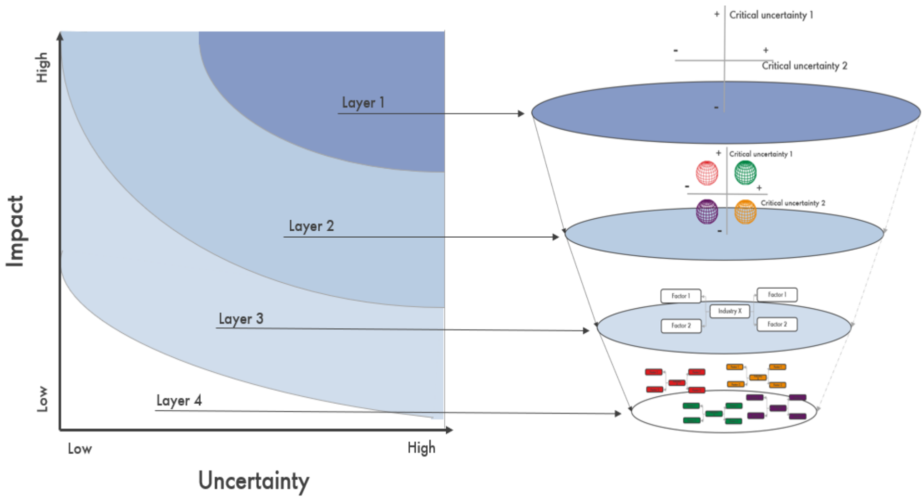

Figure 2: Linking the impact-uncertainty matrix to the layers indicated within scenarios

If the impact is high the uncertainty should be incorporated within layer 1 or 2, if the impact is low layer 3 or 4 should be considered. Depending on the uncertainty, layer 1 (high uncertainty) or 2 (low uncertainty) and 3 (high uncertainty) or 4 (low uncertainty) is chosen.

4. Dynamic scenario framework

To apply the concepts introduced during an update, several steps need to be performed. This section discusses the different steps that together form the proposed theoretical framework and attempts to close the gap within literature by offering a structured process for taking the changing environment into account within scenarios; a topic that is currently under-explored.

Figure 3 presents the entire process consisting of 7 steps. The first two steps are performed to understand the current scenarios and their buildup. The third step is executed to understand the changing external environment and provides the required input for performing an update. The 4th step is the first part of incorporating the external environment into scenarios by adjusting the assumptions in layer 4, referred to as a regular update. Within step 5 and 6, new trends and uncertainties not yet considered within the scenarios are dealt with by determining *if* and *how* these should be considered within the scenarios. Lastly, the changes are validated in step 7. Each step is briefly discussed.

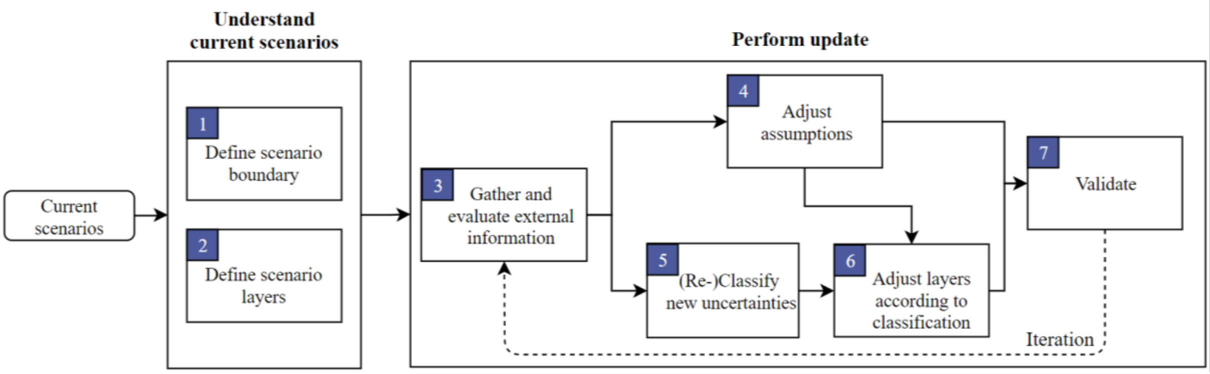

Figure 3: Dynamic scenario framework

Step 1

The first step within the framework is to define the boundary of the scenarios and is referred to as the context in which the scenarios were generated. Defining the scenario boundary is done by discussing the scope and focus area within the scenarios. The scope can refer to a geographical location and timeframe, while the focus area is related to what is found important within the scenarios. Additionally, the objective of defining the scenarios should be highlighted. This helps to keep focus when performing an update. Moreover, by repeating the goal it justifies certain choices made during the update.

Step 2

The second step within the framework is to define the scenario layers. The structure of the current scenarios should be identified before performing any alterations. Each layer should be individually formulated to indicate their characteristics. Additionally, it is important to highlight the interdependency within and between the layers. An input of this layer is the current set of scenarios. Identifying the different layers within the scenarios before performing any alterations provides the basis of being able to structurally perform an update as this structure influences how changes should be incorporated.

Important to note is that step 1 and 2 are executed once when the framework is used for the first time. When the boundary and the different layers are indicated, these can also be used during other updates.

Step 3

When performing an update, new information and uncertainties are considered. Without retrieving any new information, an update cannot be performed. The main goal of retrieving this information is to understand the changes within the environment and the impact of these change on the scenarios. Additionally, it provides the input for executing this update. This step consists of two parts: 1) gathering information on assumptions made within the scenarios and 2) gathering information on new uncertainties not yet considered within the scenarios.

When the information is gathered on the assumption made it should be evaluated if a regular update suffices (step 4) or the impact-uncertainty matrix is needed, indicating a new trend is found (step 5 and 6). Evaluation should start at layer 4 as this layer is subjected to rapid changes and the assumptions within this layer are most likely to change, while the assumptions in higher layers can still be valid. In most cases, changes made at a lower layer will not necessarily impact any of the layers above. If this update is performed after a short period of time (couple of years), the second layer may not need any alteration as this layer discusses the more long-term macro perspective. Nonetheless, if a lower layer is often being updated, this might highlight a possible new trend that is currently being ignored at a higher layer. Re-evaluating the assumptions within higher layers may then be needed to capture this trend and the lower route within the framework must be taken. This, therefore, requires the uncertainty to be re-classified onto the impact-uncertainty matrix and re-evaluate all the assumptions made related to this uncertainty.

New uncertainties, not yet incorporated within the scenarios, always require the use of the impact-uncertainty matrix (step 5 and 6) and, therefore, do not require any further analysis here.

Step 4

Within step 4, external information is considered within the scenarios by adjusting the assumptions in layer 4, thereby performing the first part of the actual update, referred to as a regular update. Updating the current assumptions within the scenarios makes sure the basis of the scenarios are relevant and plausible before incorporating new uncertainties. The previous steps prepare this process to be executed in a structured way.

Step 5

As the external environment changes, new uncertainties, not yet considered within the scenarios, may have arisen. Within this step, the impact-uncertainty matrix is used to evaluate *if* and *how* these uncertainties must be considered. Additionally, if a historical update was already performed using the impact-uncertainty matrix, it should be checked if the uncertainties classified then, are still assigned with the same level of impact and uncertainty. Uncertainties not found relevant during the last update might have evolved and become more relevant, moreover, some relevant uncertainties might have become less relevant. Classifying these changes forces the scenario planners to think about its impact and uncertainty and thereby the possible influence on the business environment. It makes sure that the right problems are addressed in the right way (in the eye of the scenario planners). The classification justifies why uncertainties are considered in a specific layer and thereby provides easy communication.

Important to note is that the impact-uncertainty matrix provides a *suggestion* into which layer these uncertainties must be considered and different experts may have differing views. It is indeed possible that one expert is convinced that the uncertainty should be considered in a different layer to another expert. This is discussed in Section 7.1.

Step 6

Step 6 performs the second phase of incorporating the external environment into the scenarios to ensure they resemble plausible and relevant future visions. By executing the update starting at the first layer, it reminds the scenario planners of the interdependency between and within the different layers and makes sure this interdependency is considered. Subsequently, by executing this step the scenario planners are reminded that besides executing a regular update by checking assumptions within the current scenarios, new uncertainties might have evolved and are important to incorporate.

Step 7

Performing an update changes the scenarios, content-wise and relatively from each other. Step 7 involves validating the changes made such that the scenarios represent a plausible relevant future and shows consistency within and between the scenarios. If after performing an update, the scenarios represent a slightly different version of the same story, the scenarios need additional changes to ensure unique and diverging scenarios. As these validation methods are often organization-specific, this research does not go into detail how this should be executed. If during validation, the validation criteria are not met, iterations are needed. This indicates that the scenarios need to be altered until the validation criteria are met.

5. Test case – scenarios discussing European power market

Thus far, this paper has theoretically argued for a framework to incorporate the external environment into scenarios. This section provides the practical dimension of this paper by applying the framework to four scenarios discussing the European power market. The main goal of presenting this test case is to illustrate how the framework should be used within a practical context, consequently highlighting the benefits of using such a framework, while at the same time uncovering any of its limitations. The presented test case is a simplified version of an entire update as a complete update would be a lengthy process and require multiple resources that are simply not available for this project.

Within the test case, hydrogen, an uncertainty not yet considered within the scenarios, is used as an example to determine *if* and *how* it should be considered within the scenarios. First, a short outline is presented of what each scenario represents, assuming step 1 and 2 are already executed. Step 3 shortly discusses the retrieved information. As step 4 resembles a regular update, new information will be added to the existing assumptions within the scenarios. This step explained but not expanded upon as this is not the focus of this paper. Step 5 and 6 will elaborate on taking this new uncertainty, hydrogen, into account. It is important to note that there are two main routes, regular update (step 4) and incorporating new trends and uncertainties (step 5 and 6). These are separate within the framework to reduce the complexity of the process and indicate there is a difference with evaluating and altering the current assumptions, and incorporating new uncertainties not yet considered within the scenarios. This second route is primary the focus of this paper as research on this topic is limited and there is currently no methodology in the literature that provides a structured process for incorporating new trends and uncertainties into scenarios.

Introduction scenarios (step 1 and 2)

In total, four scenarios are explored during this test case: *Base case, Regulator, Factory and Rocket*, each describing a plausible unique pathway of the European electricity market from 2016 - 2050. As these scenarios were generated a few years ago, since then, new uncertainties have arisen, and new information has become available.

Base case represents a central view on the evolution of the power market, in line with current trends and can be seen as the reference scenario. *Rocket* is a world in which decarbonization takes precedence and is pursued across all sectors through a diversified mix of low carbon generation, reaching the Paris agreement, and is seen as a high case. *Factory* is a consumer-driven world in which delayed decarbonization occurs through small-scale low carbon generation and is seen as a low case. *Regulator* is a policy-driven world in which decarbonization occurs through large-scale low carbon generation. This world results in an intensive policy intervention in the energy sector which are more often successful than not. Figure 4 represents these scenarios plotted onto the *Framework* (layer 1) to highlight the differences in terms of the two chosen critical uncertainties.

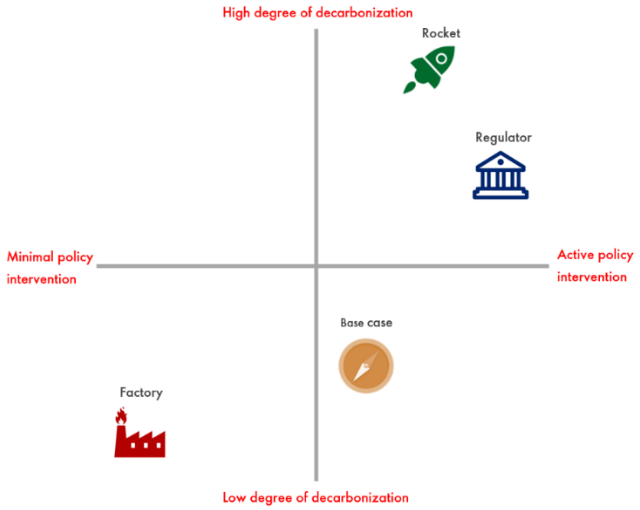

Figure 4: Scenarios plotted onto framework

Hydrogen is used as an example, as it is thought it applications might influence the power market in Europe and is currently no considered within the scenarios. To understand how hydrogen applications might influence the European power market and thereby the scenarios, external information should be retrieved (step 3).

Step 3 – Retrieve and evaluate external information

Hydrogen

Electricity is currently the main energy carrier considering wind and solar energy. Balancing the grid can become an increasingly complex task with the intermittent character of these sources combined with the inability to store electricity at large scale (Schwenen, 2018). Hydrogen is an alternative energy carrier that can be produced from water using electricity and can be stored in large quantities for long periods (European Commission, 2019). This could help increase the flexibility of the energy system by balancing during abundance or deficits of power. Hydrogen is already being used within industry for a long period of time and this experience is now used to introduce hydrogen in civil situations (RVO, n.d.).

In total three main production methods are identified for hydrogen; green, blue and grey. Green hydrogen is the emission-free method in which hydrogen is produced via electrolysis using electricity from renewable energy sources. Blue hydrogen refers to a climate-neutral method producing hydrogen using natural gas where the released carbon is captured using carbon capture storage (CCS) (CE Delft, 2018). The most often used and least expensive method is grey hydrogen in which fossil fuels are used to generate hydrogen and is thereby also the most polluting method (Acar & Dincer, 2014).

Within the EU a hydrogen economy is already gradually developing. There are currently a numerable amount of hydrogen projects generating or implementing blue or green hydrogen, especially in Europe (New Energy Coalition & JIN Climate and Sustainability, 2019). However, even though hydrogen investments are present there is a mixed view on the importance of hydrogen in the future. Dorian, Franssen, and Simbeck (2006) state that while hydrogen is attractive from an environmental point of view it is expensive to produce, transport, store and distribute and therefore requires a technological breakthrough for a hydrogen economy to emerge.

As the test case refers to the electricity market in Europe, it is important to understand how hydrogen may influence the evolution of the electricity market. Providing green hydrogen could boost the use of solar and wind energy, by offering opportunities to balance the grid during abundance or deficits, allowing for increased electricity production (IRENA, 2018; PBL, 2011). The hydrogen council (2017, p.10) even states that *"By 2030, 250 to 300 TWh of surplus renewable electricity could be stored in the form of hydrogen for use in other segments."* However, if a hydrogen economy emerges, when produced from fossil fuels, it would reduce demand for electricity. It is therefore not only the question of *if* a hydrogen economy will emerge but also *how* this hydrogen will be produced.

Step 4 – Adjust assumptions

When executing an update, in step 3 all assumptions within layer 4 should be analyzed using new information (currently not discussed due to time constraints). If the conclusion after analyzing the information is to update these assumptions, this should be executed within step 4. As this is not the focus within this paper, an example is provided within Appendix B. This example refers to the assumptions made within the scenarios on installed capacity of solar PV.

Step 5 – Classify new uncertainties

To determine *if* and *how* hydrogen should be considered within the scenarios discussed, multiple power experts were asked to discuss how they would assess the uncertainty and impact of hydrogen on the European electricity market. The outcome is briefly discussed (figure 5).

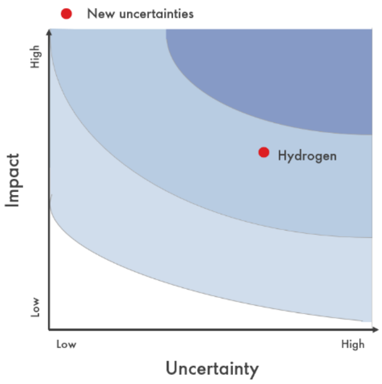

Figure 5: Matrix with hydrogen classified

While the impact of hydrogen on the electricity market can be relatively high, there is no one answer on how hydrogen will evolve in the future. The uncertainty is classified as medium-high with the impact on the electricity market also medium-high. Hydrogen should, hence, be considered within layer 2. The purpose of taking hydrogen into account within the different scenarios is to discover multiple pathways hydrogen could take to deal with this uncertainty.

Step 6 – Adjust layers according to classification

Adjust layer 2

Hydrogen is incorporated within the second layer and, therefore, changes the storylines. As hydrogen is only a small part of the entire storylines, the part that is added to the existing storylines is discussed in Appendix C. These storylines are constructed using the external information retrieved and fitted into the worlds the scenarios represent. Additionally, multiple scenario-specific assumptions are formulated and shown in Appendix D.

Adjust layer 3

As hydrogen is considered within the second layer, it also influences the third layer. Updating the third layer discusses the question of which factors are influenced by introducing hydrogen into the market.

There are many factors indicated to influence the evolution of the power market in Europe that were defined by constructing the flowchart in step 2. The flowchart is shown in Appendix E. Within an entire update each factor should be individually questioned by discussing the possible influence of introducing hydrogen. Here some examples are provided of the possible influence of hydrogen on the electricity demand from the transport sector.

1) *% Electrification end goal 2050* As stated, hydrogen may increase electricity demand in two different ways. First, hydrogen provides the ability to balance the grid, therefore, an increase in renewable energy sources is possible without balancing. Secondly, if hydrogen is produced in a green way, demand might also increase. Both reasons might influence the path towards the *percentage of electrification end goal 2050*. The growth of electricity demand by hydrogen might increase the pace of electrification. However, this factor is scenarios specific and therefore depends on how the scenario depicts a hydrogen economy. A scenario in which grey hydrogen is extensively used, the percentage of electrification might even slightly reduce as it steals some market share of electricity.
2) *Vehicle km driven* is not necessarily influenced by the amount of hydrogen used, nonetheless, an abundance of very cheap hydrogen may lead to an increase in the amount of km driven. However, this effect is not considered here.

Adjust layer 4

The question to what extent hydrogen influences the factors identified in layer 3, is discussed in the layer 4. Within this layer we, quantitatively, distinguish the impact of hydrogen between the scenarios to mitigate for its uncertainty. Each factor on which hydrogen has an influence should be defined with numbers using the extern information retrieved with the formulated storylines as a basis. As there are many different factors within the flowchart influenced by introducing hydrogen, one example is provided to illustrate the process. This example refers to the electricity demand from trains.

The question within this example refers to how hydrogen might influence the electricity demand for trains in Europe. To answer this question extensive research should be executed. The research showed that hydrogen-fueled trains have a high potential in non-electric railway with a commercial increase around 2030 (Hydrogen Council, 2017). It is thought not to compete with electricity but might complement electrified trains, resulting in a boost for electricity demand if produced using renewables (IRENA, 2018). To calculate how much electricity demand is additionally generated, the information retrieved and the storylines from the scenarios are used to formulate the percentage of possible trains power by green hydrogen (Table 1).

Table 1: Scenario-specific assumption on % of trains power by green hydrogen

% of trains fueled by green hydrogen								
Scenario	2016	2020	2025	2030	2035	2040	2045	2050
Base case	0%	0%	0%	0%	1%	2%	3%	5%
Rocket	0%	0%	0%	1%	4%	6%	11%	16%
Regulator	0%	0%	0%	2%	5%	8%	15%	20%
Factory	0%	0%	0%	0%	0%	0%	0%	0%

To calculate the effect of hydrogen-powered trains on the electricity demand, the following formula is used:

*Electricity demand from hydrogen trains = (% of trains fueled by green hydrogen * (total km driven by trains * hydrogen usage per km * kWh of electricity per kg h2 production)) / 1000*

The following data is used to calculate additional electricity demand from hydrogen-powered trains.

Table 2: Additional information to calculate electricity demand from hydrogen trains

Total Km driven by train[1]	
in million	
Belgium	59
Denmark	63
France	260
Germany	573
Netherlands	116
UK	371
Total	**1442**

kWh of electricity per kg H2 [2]		Comments
2017	54	Average taken
2030-2050	45	

hydrogen usage [3 4]		Comment
kg hydrogen per km		For lightweight or passenger transport
2018	0.3	
2030-2050	0.25	

[1] European Rail Research Advisory Council, 2016
[2] IRENA, 2018
[3] Shirres, 2018
[4] Roland Berger, 2019

Using the values provided in table 2 and the formula indicated. The additional total electricity demand from hydrogen for each scenario is calculated and shown in table 3.

Table 3: Additional electricity demand from hydrogen-power trains

Additional electricity demand from hydrogen powered trains								TWh
	2016	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Base case	0.00	0.00	0.00	0.00	0.00	0.16	0.49	0.81
Rocket	0.00	0.00	0.00	0.16	0.65	0.97	1.78	2.60
Regulator	0.00	0.00	0.00	0.32	0.81	1.30	2.43	3.24
Factory	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

The outcome provides us with the total scenario-specific electricity demand from hydrogen-fueled trains and should, therefore, be added to our current view of electricity demand from trains. In this example, only one factor within the entire flowchart is investigated. During a real update every factor should be closely examined also taking into account the interdependencies between the factors; changing one factor might influence other factors as well.

6. Results

The results discuss how successful the framework is in structurally incorporating new information and uncertainties into scenarios by judging the process of executing the test case. It was argued a structured process would increase time-efficiency, provide a common language for incorporating changes and would make the process more transparent. Additionally, it would reduce some of the complexity of the process. Focus is, therefore, placed on these criteria to evaluate the process. Moreover, the test case was validated by multiple experts who have themselves executed multiple scenario updates and asked if there was any added value for them to use such a framework.

Overall benefits

1. Easy to understand interdependencies within and between the scenarios

During an update, it is important to understand the interdependencies within and between the scenarios. By defining the layers, it does not only become apparent what the differences and similarities between the scenarios are but also what the structure is within a single scenario. This highlight and reminds the scenarios planners of the importance of this interdependencies; if one factor changes, other factors might also be influenced.

2. Use of impact-uncertainty matrix provides useful tool

The use of the impact-uncertainty matrix and its link to the different scenarios, provides a good structure to solve a difficult question: what is the influence of considering these uncertainties on the scenarios? The link provides a structure in understanding how these changes might influence the scenarios, therefore, reduces some of the complexity of the process.

3. More time-efficient

Using the framework proposed, the discussion on *if* and *how* changes should be incorporated and will be less time-consuming. For each change it is decided if a regular update suffices or if the impact-uncertainty matrix is needed. Additionally, using this framework, it is immediately clear which other factors might be influenced when changing one factor. Especially the flowchart provides a good overview of which factors to focus on, without the need to review all factors. Subsequently, as some changes are suggested to be incorporated within the lower layers, it saves time reviewing the entire scenario.

4. Reduces the complexity of the process

By providing a step-by-step process of performing an update, the complexity of such a process is reduced. As the complexity of performing an update is high, standardization is preferred as it allows the user to structurally think how to consider changes, thereby reduce possible failures. Moreover, using the framework, updating the scenarios can be divided into multiple smaller steps while maintaining overview.

5. Increases transparency

One of the main results is that the framework increases the transparency of the updating process. Scenarios are formulated to understand the uncertainty surrounding the future and use these insights for strategic decisions. As the people updating and formulating scenarios are often different than the ones making decisions from its outcome, communication changes made is important. Making the process easy to understand, simple and logical, was therefore one of the objectives when generating the framework. The framework has created a common language for incorporating new information and uncertainty, thereby, improves communication. It was easy to explain which steps had been performed and why certain choices were made, as the steps are clearly indicated, and these choices were made using the tools described. Using the framework, the updating process becomes explainable and transparent. The framework therefore not only reduces some of the complexity of the update but also increases the transparency, thereby, making it easier to communicate to the outside world.

Overall improvement points

1. Classifying changes onto impact-uncertainty matrix

When classifying changes onto the impact-uncertainty matrix, it was shown the opinions of the experts were not uniform. The classification represents the importance of a subject in the eye of these scenarios planners and is therefore subjected to opinion. Assigning a certain level of impact and uncertainty might therefore be difficult.

2. Acquiring information is time-consuming

An important step within the framework is to retrieve external information. Retrieving this information was very time-consuming and sometimes difficult. Due to the abundance of information is might be difficult to understand what information is important and what not.

3. Lack of information to use framework

Additionally, when scenarios are generated, it is often not registered which sources are used to formulate the different assumptions. Formulating the layers might then be difficult due to the lack of information on how certain conclusions were drawn. It was therefore a difficult and time-consuming process to visualize and describe the different layers. However, this also describes the need for such a structure.

7. Discussion

The literature clearly makes a distinction between how changes are considered into scenarios, however, fail to address how they execute this assessment. This research gap was addressed by proposing to use of the impact-uncertainty matrix to classify changes and is an important part of the proposed solution. However, the choice for this tool has several implications that require attention: (1) *How an update is performed is highly dependent on how one categorizes uncertainties within the impact-uncertainty matrix:* depending on the views of the people classifying the uncertainties, the resulting update could be performed differently. One could argue using this tool, highly influences how an update is performed. The question however is whether this should be considered a limitation. An update that requires several people will always be influenced by their views and opinions regardless of whether the impact-uncertainty matrix is used or not. While the matrix provides a tool to structurally translate these views, it does not provide a means to reach consensus in the way uncertainties should be classified and hence how an update should be performed. (2) *Difficult to assign a certain level of impact and uncertainty*. Following point one, the opinions on the level of impact and uncertainty assigned to an issue may not be uniform. It is important to note that a perfect prediction of the amount of impact and uncertainty would mean to foresee the future and therefore is not possible. However, it may be important to indicate some criteria to help steer the discussion. For example, if the size of the market on which the uncertainty has an impact is small, the impact on the entire industry might also be small. (3) *The validity of one-to-one link with scenario layers.* Within this research, a one-to-one link is suggested from the impact-uncertainty matrix to indicate in which layers the issues need to be considered. The question might arise if this one-to-one link is always valid. This link was made based on literature (Krueger et al., 2001; Van Vuuren et al., 2010) and the characteristics of the layers defined (Geels, 2002). The lines within the matrix provide a *suggestion* onto which layer the changes need to be incorporated and should not be seen as conclusive. It provides a tool to structurally think on how the uncertainties impact the scenarios. It might happen scenario planners classify an uncertainty onto the matrix and not agree to consider within the assigned layer. During the test case, such a situation has not occurred, and it has provided a good tool to translate the opinions surrounding an uncertainty into a suggestion *if* and *how* they should be considered within the scenarios.

Additionally, the framework proposed is influenced by the personal opinion of the author. It is important to note that there is no definitive procedure for updating scenarios and it is not suggested that the framework presented is the only “right” methodological approach possible. It should be seen as a tool to help structure the complex process of updating scenarios, thereby, reduce some of its complexity.

Another point that requires attention is the fact that the process of performing an update, using the framework, is still very open. The framework is used to guide the process of keeping scenarios up-to-date, but the updating itself completely depends on the people executing the update.

8. Conclusion & Future work

To structurally incorporate new information and uncertainties into scenarios, keeping them up-to-date, guaranteeing that the scenarios remain realistic and useful, a framework consisting of 7 steps is developed. The framework aims to offer the user a tool that helps you to think about *if* and *how* changes should be incorporated within scenarios and what the impact of these changes are for the rest of your scenario.

Using the framework allows the complexity of the update to be simplified in a step-by-step process. For each change it is decided if a regular update suffices or if the impact-uncertainty matrix should be used to understand *if* and *how* they should be considered within the scenarios. By separating the update in smaller concrete steps, understanding how these steps influence the rest of the scenario, a major part of the complexity is reduced. Subsequently, when using the framework, the process becomes increasingly transparent. Increasing the transparency of the process increases understanding of the scenarios itself and changes made, thereby, making the process explainable and justifiable, on why and how choices are made. The framework proposed does not only increase the transparency of keeping the scenarios plausible and relevant for the scenario planners, but also creates a language for communicating it to a broader audience. Scenarios are constructed to understand the uncertainty within the future used as a basis for making decisions. The layers proposed triggers people to think differently towards scenarios, taking a step back from the complex components and creating an overview of their main purpose and views discussed. This could help more people to better understand the scenarios itself and their outcome, thereby creating mutual understanding. Knowledge and insights should be shared, and collective actions should be taken to reduce environmental change. The dynamic scenario framework provides a small part of better understanding the consequences of our actions today for our future tomorrow.

The work presented within this paper has fulfilled the research aims which were initially defined. However, due to the research findings and the indicated limitation, several questions have arisen and remain to be answered. Therefore, there are some areas in which further research is recommended to further develop the framework:

As highlighted in the discussion, classifying a change onto the impact-uncertainty matrix is subjected to opinion. Many articles indicate the use of the impact-uncertainty matrix to identify critical uncertainties, however, they rarely mention how this uncertainty and impact needs to be assigned (Benedict, 2017; WSP, 2018; Quiceno et al., 2019). Pillkahn (2008), therefore, rightfully argues there is a lack of suitable criteria for identifying differences between changes. Further research could focus on formulating criteria to help steer discussion. This could move forward discussion surrounding many different opinions.

Additionally, further research needs to be carried out to validate the choice of the impact-uncertainty matrix. There are many other tools to classify changes, and the choice for this tool was the ability to link it to the different layers within the scenarios and the fact that this tool is well-known and simple to use. However, other tools might also be suitable for classifying changes and linking them to the different layers within the scenario.

The last recommendation refers to the development of a generic framework. A natural progression of this work is to apply the framework to scenarios discussing other industries. The test case was applied to the scenarios representing the European power market. However, to confirm the generalizability of the framework, it should be applied to other markets. Although the results may not be generically interpreted, using the framework, an update was successfully executed. The results provide a starting point for other scenarios to be structurally updated.

References

Acar, C., & Dincer, I. (2014). Comparative assessment of hydrogen production methods from renewable and non-renewable sources. International Journal of Hydrogen Energy, 39(1), 1–12. https://doi.org/10.1016/j.ijhydene.2013.10.060

Amer, M., Daim, T. U., & Jetter, A. (2013). A review of scenario planning. Futures, 46, 23–40. https://doi.org/10.1016/j.futures.2012.10.003

Benedict, B. A. (2017). Benefits of Scenario Planning Applied to Energy Development. Energy Procedia, 107, 304–308. https://doi.org/10.1016/j.egypro.2016.12.157

Bentham, J. (2014). The scenario approach to possible futures for oil and natural gas. Energy Policy, 64, 87–92. https://doi.org/10.1016/j.enpol.2013.08.019

Cardoso, J. F., & Emes, M. R. (2014). The Use and Value of Scenario Planning. Modern Management Science & Engineering, 2(1), 19–42. Retrieved from https://pdfs.semanticscholar.org/808f/7cf3831282477db9003c597df130a596b5b1.pdf

CE Delft. (2018). Waterstofroutes Nederland.

Chermack, T.J., Lynham, S.A. & Ruona, W.E.A., (2001). A Review of Scenario Planning Literature. *Futures*, pp.7–31.

Cornelius, P., Van de Putte, A., & Romani, M. (2005). Three Decades of Scenario Planning in Shell. California Management Review, 48(1), 92–109. https://doi.org/10.2307/41166329

Creutzig, F., Agoston, P., Goldschmidt, J. C., Luderer, G., Nemet, G., & Pietzcker, R. C. (2017). The underestimated potential of solar energy to mitigate climate change. Nature Energy, 2(9). https://doi.org/10.1038/nenergy.2017.140

Dorian, J. P., Franssen, H. T., & Simbeck, D. R. (2006). Global challenges in energy. Energy Policy, 34(15), 1984–1991. https://doi.org/10.1016/j.enpol.2005.03.010
European Commission. (2019a, June 28). Hydrogen. Retrieved August 7, 2019, from https://ec.europa.eu/energy/en/topics/technology-and-innovation/energy-storage/hydrogen
European Rail Research Advisory Council. (2016). Regional and Suburban Railway Market Analysis Ipdate. Retrieved from https://www.uitp.org/sites/default/files/cck-focus-papers-files/Regional%20and%20Suburban%20Railways%20Market%20Analysis.pdf
EurObserv'ER. (2018). Photovoltaic barometer 2018. Retrieved from https://www.eurobserv-er.org/photovoltaic-barometer-2018/
EurObserv'ER. (2019). Photovoltaic barometer 2019. Retrieved from https://www.eurobserv-er.org/photovoltaic-barometer-2019/
Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Research Policy, 31(8-9), 1257–1274. https://doi.org/10.1016/s0048-7333(02)00062-8
Hydrogen Council. (2017). Hydrogen - scaling up. Retrieved from http://hydrogencouncil.com/wp-content/uploads/2017/11/Hydrogen-scaling-up-Hydrogen-Council.pdf
IEA. (n.d.-a). Our Mission. Retrieved June 5, 2019, from https://www.iea.org/about/
IEA. (2014). World Energy Outlook 2014. Paris, France: OECD.
IEA. (2016). World Energy Outlook 2016. Retrieved from www.iea.org
IEA. (2018). World Energy Outlook 2018. Retrieved from www.iea.org
IPCC. (2005). Workshop on New Emission Scenarios (Meeting report). Retrieved from https://www.ipcc.ch/site/assets/uploads/2018/05/ipcc-workshop-2005-06.pdf
IRENA. (2018). HYDROGEN FROM RENEWABLE POWER. Retrieved from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Sep/IRENA_Hydrogen_from_renewable_power_2018.pdf
ITER. (n.d.). Fusion. Retrieved August 14, 2019, from https://www.iter.org/sci/whatisfusion
Krueger, R. A., Casey, M., Donner, J., Kirsch, S., & Maack, J. N. (2001). Social Analysis Selected Tools and Techniques (Paper Number 36). Retrieved from http://siteresources.worldbank.org/INTCDD/Resources/SAtools.pdf#page=68
Leggett, J., Pepper, W. J., & Swart, R. J. (1992). Emissions Scenarios for the IPCC: an Update. Retrieved from https://www.ipcc.ch/site/assets/uploads/2018/05/ipcc_wg_I_1992_suppl_report_section_a3.pdf
New Energy Coalition, & JIN Climate and Sustainability. (2019). The Dutch Hydrogen Economy in 2050. Retrieved from https://newenergycoalition.org/wp-content/uploads/2019/07/The-Dutch-Hydrogen-Economy-in-2050-July-2019.pdf
PBL Netherlands Environmental Assessment Agency. (2011). Naar een schone economie in 2050: routes verkend. Retrieved from https://www.pbl.nl/sites/default/files/cms/publicaties/pbl-500083014-verkenning-routes-schone-economie-2050.pdf
Pillkahn, U. (2008). Using Trends and Scenarios as Tools for Strategy Development: Shaping the Future of Your Enterprise. Retrieved from file:///C:/Users/Paulien.vandenBerg/Downloads/VB6JIGBQRPVNH3Z4W7GT.pdf
Quiceno, G., Álvarez, C., Ávila, R., Fernández, Ó., Franco, C. J., Kunc, M., & Dyner, I. (2019). Scenario analysis for strategy design: A case study of the Colombian electricity industry. Energy Strategy Reviews, 23, 57–68. https://doi.org/10.1016/j.esr.2018.12.009
Roland Berger. (2019). STUDY ON THE USE OF FUEL CELLS & HYDROGEN IN THE RAILWAY ENVIRONMENT (Report 1). Retrieved from https://shift2rail.org/wp-content/uploads/2019/04/Report-1.pdf
RVO. (n.d.). Who is Who Hydrogen and Fuel Cells in the Netherlands. Retrieved August 7, 2019, from https://www.rvo.nl/sites/default/files/bijlagen/Folder%20Who%20is%20Who,%20Hydrogen%20and%20Fuel%20Cells%20in%20the%20Netherlands.pdf
Schoemaker, P. J. H. (1991). When and how to use scenario planning: A heuristic approach with illustration. Journal of Forecasting, 10(6), 549–564. https://doi.org/10.1002/for.3980100602
Schwenen, S. (2018). Electricity Market Architecture [College-slides]. Retrieved March 28, 2019, from https://www.moodle.tum.de/pluginfile.php/1700306/mod_resource/content/0/Lecture6_slides.pdf
Shirres, D. (2018, January 5). Hydrail comes of age. Retrieved September 3, 2019, from https://www.railengineer.co.uk/2018/01/05/hydrail-comes-of-age/
Speziale, L., & Geneletti, D. (2014). Applying an ecosystem services approach to support land-use planning: a case study in Koboko district, Uganda. Ecological Processes, 3(1). https://doi.org/10.1186/2192-1709-3-10
Van Vuuren, D. P., Edmonds, J., Smith, S. J., Calvin, K. V., Karas, J., Kainuma, M., Nebojsa, N., Keywan, R., Van Ruijven, B. J., Swart. R., Thomson, A. (2010). What do near-term observations tell us about long-term developments in greenhouse gas emissions? Climatic Change, 103(3-4), 635–642. https://doi.org/10.1007/s10584-010-9940-4
Van Vuuren, D. P., & O'Neill, B. C. (2006). The Consistency of IPCC's SRES Scenarios to 1990–2000 Trends and Recent Projections. Climatic Change, 75(1-2), 9–46. https://doi.org/10.1007/s10584-005-9031-0
Verschuren, P. J. M., & Doorewaard, H. (2010). *Designing a research project*. Retrieved from https://epdf.tips/designing-a-research-project-second-edition.html

WSP. (2018). Decision-Making for Alternative Futures. Retrieved from https://www.wsp.com/en-gl/news/2018/wsp-unveils-future-ready-approach-to-decision-making?_ga=2.90642076.781673322.1564150572-1530025110.1564150572&_ga=2.90642076.781673322.1564150572-1530025110.1564150572

Wilson, I. (1983). The benefits of environmental analysis. In Kenneth J. Albert (Ed.), Strategic management handbook (pp. 9-1 to 9-19). New York: McGraw-Hill

Appendix A – Summary of layer characteristics of scenarios

Table 4: summary of different layers within scenario

1. Layer	2. Goal of defining this layer	3. Main characteristics of layer	4. Output when defining this layer	5. Impact of changes in this layer on scenario	6. Validation after change
Framework Layer 1	Let's you think about the basis on which the scenarios are built (extremes of critical uncertainties) and provides inside on context defined for other layers.	• Defines most pressing issues within industry (high impact & high uncertainty) • Long-term problems • Not subjected to rapid changes - decades - (relatively stable layer) • Outside direct influence of other layers • Macro-perspective – discusses problems effecting entire market	• Framework indicating two critical uncertainties and their extremes • Assumptions why these critical uncertainties are chosen	The entire set of scenarios need to be checked and/or redesigned and therefore all lower layers change.	Same validation process as when generating completely new scenarios
Storyline Layer 2	Let's you think about how the storylines are currently structured and how these scenarios differ relatively from each other. This layer defines in more detail (compared to layer 1) how the future might unfold.	• Describes qualitatively how the future might develop form present to end state • Defines how critical uncertainties might evolve in different ways • Macro-perspective • Not subjected to rapid changes – years. • Outside of direct influence of lower layers but highly influence by top layer	• Short outline of storylines (indicating differences, type and what these storylines represent) • Matrix with scenarios plotted representing how critical uncertainties unfold per scenario • Scenario-specific assumptions	One or multiple qualitative scenarios would need to be redesigned. As a consequence of these changes, the lower two layers also need to be changed.	Check each individual scenario if still present plausible future & check how they have changes relative to each other and if they still add different perspectives
Industry specific fundamentals Layer 3	Let's you think about which factors influence your industry and helps to visualize the interdependency of these factors. Additionally, it creates insight into how the qualitative scenario is translated to the quantitative scenario.	• Visualized structure of industry/factor of interest • Shows interdependencies between factors • Highlights current technologies used • Subjected to relatively fast changes – months, years – • Changes are related to industry changes • Focal points indicated relate to pressure of higher layers	• Flowchart visualizing industry specific fundamentals and their relations • Assumptions	All quantitative scenarios need to be redesigned. Besides that, if multiple changes are incorporated the storyline might also be influenced (over time)	Check if factors indicated still add up. Does the flowchart still represent the industry structure in a plausible way
Numbers Layer 4	Let's you think about how the different numbers in the quantitative scenarios are constructed.	• Describes quantitatively how the future might develop form present to end state • Subjected to rapid changes – days, months • Macro- and micro perspective • Pressure from all layers above • New innovations are introduced here but might not directly influence industry structure	• Numbers attached to factors in flowchart specific for each scenario • Assumptions on which this layer is built • Sources used to formulate scenario-specific numbers	Change one or multiple quantitative scenarios.	Check if the quantitative scenarios still represent a relevant, plausible consistent set.

Appendix B – Example step 4 (regular update)

Assumptions on electricity generation by solar PV before update.

Table 5: Scenario-specific assumptions – electricity generation by solar PV

Electricity generation by solar PV						**Source: IEA 2016**					
GW											
Scenarios	**2016**[5]	**2017**	**2018**	**2019**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Base case	101.0	105.3	109.5	113.8	118.0	136.0	150.0	160.0	166.0	173.0	180.0
Rocket	101.0	108.8	116.5	124.3	132.0	148.3	164.7	181.0	197.3	213.7	230.0
Regulator	101.0	106.5	112.0	117.5	123.0	135.8	148.7	161.5	174.3	187.2	200.0
Factory	101.0	104.3	107.5	110.8	114.0	121.7	129.3	137.0	144.7	152.3	160.0

Assumptions on electricity generation by solar PV after update. The numbers for the years 2016 – 2018 are the same for each scenario as it is known for these years how much solar PV was installed. Additionally, the numbers for the years 2019 - 2050 are slightly altered according to the new insights and information gathered in step 3. Since our *Rocket* and *Regulator* scenario represent our high view, these scenarios will have the largest increase while the *Factory* scenario has a small increase. This ensures the scenarios still represent different views. The final values for 2050 are increased for *Rocket* with 20 GW, *Regulator* with 15, *Base case* with 10 and *Factory* with 5. From there the values are linearly decreased until the values for 2018. The values for 2016- 2050 are the same for all scenarios.

Table 6: Alterations scenario-specific assumptions electricity generation by solar PV

Electricity generation by solar PV						View from 2016					
GW											
Scenarios	**2016**[5]	**2017**[6]	**2018**[7]	**2019**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Base case	101.0	107.0	115.0	124.4	133.8	143.1	152.5	161.9	171.3	180.6	190.0
Rocket	101.0	107.0	115.0	131.9	148.8	165.6	182.5	199.4	216.3	233.1	250.0
Regulator	101.0	107.0	115.0	127.5	140.0	152.5	165.0	177.5	190.0	202.5	215.0
Factory	101.0	107.0	115.0	121.3	127.5	133.8	140.0	146.3	152.5	158.8	165.0

[5] IEA, 2016
[6] EurObserv'ER, 2018
[7] EurObserv'ER, 2019

Appendix C – Scenario-specific storylines for hydrogen

Rocket

Due to the large increase of intermittent solar and wind, exploring options to use hydrogen for balancing the grid has grown. From 2030, there is a steady increase of green hydrogen use as a result of sharp cost reductions due to technical improvement and cheap electricity from renewables (lower cost of production). Additionally, efficiency (from transforming electricity to hydrogen and back) has improved which increases the attractiveness of using green hydrogen. Especially within the heavy-weight transport sector the use of hydrogen increases, as this is more efficient than electric vehicles. Due to this increased use of green hydrogen, electricity demand increases. However, as hydrogen is less stimulated by the government than within *Regulator*, hydrogen will take a slower introduction into the market.

Base case

Due to the advantages of hydrogen to balance the grid, there is a slight increase in hydrogen use, however, not enough to push down costs to make it available on large scale. Hydrogen is mostly produced using cheap gas. Within industry blue hydrogen is stimulated over grey hydrogen to reduce pollution, but only after 2040. Additionally, there are multiple small initiatives, driven by real business cases, that finds market share, however, without any real impact (e.g. forklifts that use hydrogen). Therefore, no large-scale projects are realized. The government stimulates the use of hydrogen as an attempt to improve security of supply and environmental sustainability but do to large costs and lacking efficiency a hydrogen economy will not take place.

Factory

Due to the lack of government support and decarbonization low on agenda, hydrogen is not explored extensively. Off-grid small scale hydrogen is used as an initiative to store electricity produced from solar panels, however, large investments, to push down costs are lacking. While grey hydrogen is increasingly being used within the industry (as this infrastructure is already largely in place), the government tries to stimulate blue hydrogen to push down emissions but fails in doing. Main barriers to implementations of green hydrogen are large sunk investments needed and efficiency losses.

Regulator

Due to large increase of intermittent energy sources and strong government intervention, hydrogen will be steadily adopted on large scale from 2030 (with significant share in 2040), therefore, cost of hydrogen has decreased steadily. Large investments are done mainly due to government support which gave a boost to infrastructure and made large scale movement of hydrogen possible. As of the large increase in the use of hydrogen, from 2030 blue and sometimes grey hydrogen is used, however, due to environmental pressure, the use of green hydrogen increases rapidly and replaces grey hydrogen completely.

Appendix D – Scenarios specific assumptions layer 2

Table 7: Scenario-specific assumption for hydrogen - layer 2

Scenario		Base case	Rocket	Factory	Regulator
Category	Sub-category				
Supply	Total hydrogen	Small growth	Medium growth 2030 after which large growth	Small growth	Large growth
	Green hydrogen	Small growth (mainly within industry but only after 2035)	From 2030 medium growth after which high growth from 2040	No growth	High growth after 2040
	Blue hydrogen	Medium increase from 2035	Small increase from 2030	Small increase	Steady increase from 2030
	Grey hydrogen	Small increase	Large decrease from 2035	Small increase	Small increase in 2030 but large decrease around 2035
Efficiency	Green hydrogen	Small improvements	Large efficiency improvements	Small improvements	Delayed efficiency improvements

Appendix E – Flowchart constructed layer 3 of scenarios

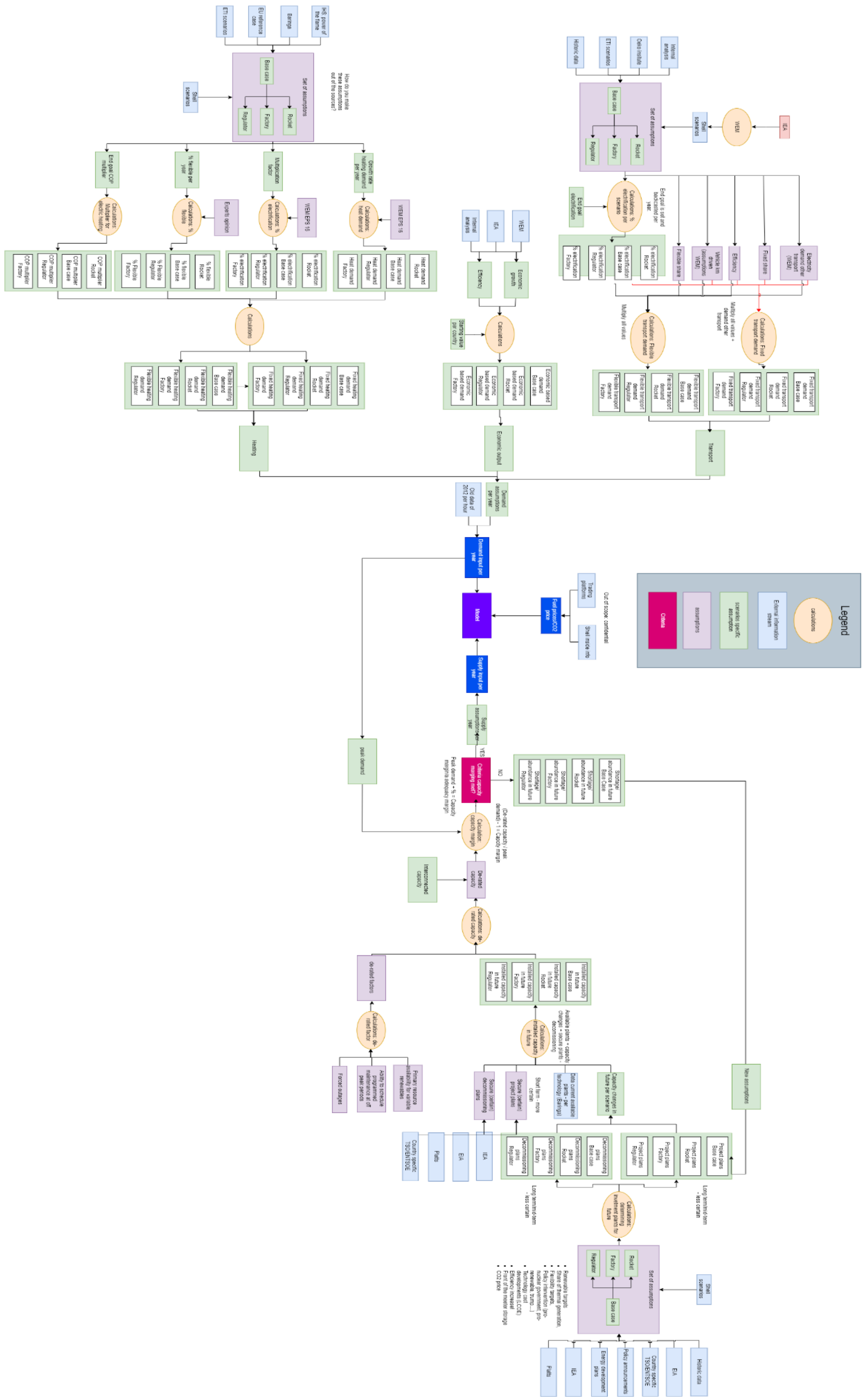

Figure 6: Flowchart – Industry specific fundamentals