

Unfolding hydrogen

An experiment with repertory grid to elicit the relevant concepts in the debate about hydrogen

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Abstract

This paper describes how repertory grid technique was used in an integrated assessment of the implementation of hydrogen in The Netherlands, in an international context. Repertory grid technique finds its origins in construct psychology and has gradually gained ground in environmental research and policy analysis too. Its basic idea is that the minds of people are 'construct systems' which reflect their constant efforts to make sense of the world. Repertory grid technique articulates the individual construct systems of people, which helps to better understand what meaning people give to the world around them. The technique was applied in this integrated assessment to elicit the relevant concepts with regard to hydrogen as an energy carrier and to reduce ten initial hydrogen visions to three visions. These three visions form the starting point of three respective stakeholder dialogue groups. The repertory grid technique was applied on a group level, in a computerized fashion. From a frequency analysis it seemed that all constructs that the participants in the repertory grid exercise used to make sense of the ten hydrogen visions were identified by means of the repertory grid technique. A HOMALS analysis was used to assess how the participants categorized the hydrogen visions. Based on the HOMALS analysis the three hydrogen visions were formulated that serve as a starting point for three dialogue groups. The paper concludes by reflecting on the procedure of the technique, the possibilities of analysis and the use of the technique in a general (policy) context.

1. Introduction

There are many different views, ambitions, and expectations in both the science and the policy domain of the potential role of hydrogen (H₂) as an energy carrier in the future energy system. These viewpoints are based on different assumptions with regard to cost effectiveness, the availability of alternatives, incentive structures, the pace of technological innovation, et cetera. Romm (2004) for instance, argues that neither government policy nor business investment should be based on the belief that hydrogen cars will have meaningful commercial success in the near or medium term, and he warns that the long-term potential of hydrogen should not become an excuse to avoid taking action in the short run to reduce greenhouse gas emissions. Also Demirdöven and Deutsch (2004) claim that, in an urban drive cycle, the fuel cell car does not offer any significant energy efficiency advantage over alternative vehicles such as hybrids. Sperling and Ogden (2004) take a different stand. They make a case for hydrogen and argue that there is no alternative option for the long term that is more compelling than hydrogen. Other researchers such as Clark and Rifkin (in press, see also Rifkin, 2002) argue that the hydrogen economy

is much closer than many scientists and bureaucrats state and stress the importance of hydrogen in the short term, in order to allow for sustainable growth.

In addition to the time frame for hydrogen, there are also different viewpoints with regard to the energy sources to produce hydrogen from, the kind of infrastructure that needs to be build, the technologies that should play a key role in the hydrogen-based energy system, the application domain for hydrogen, and many other aspects of the envisaged 'hydrogen economy'. Overall, one could say that the discussion on hydrogen is characterized by different views, scientific uncertainties, controversies, conflicting interests, and power issues, which makes it difficult to develop an integrated insight into the state of affairs with regard to hydrogen. In order to get such an integrated insight, and to identify the real problems and potential solutions to these problems, a research team in the Netherlands has started an integrated assessment of the implementation of hydrogen in the Netherlands, in an international context¹. The three authors of this article are members of the research team. In this article, we report on the experience that we gained with a particular method that was used in the assessment process: the repertory grid technique. Repertory grid is a method that originates from construct psychology and that was used in the project to articulate stakeholders' views on hydrogen futures. In this article we particularly want to explore to what extent repertory grid managed to facilitate the selection of three visions and to elicit the whole range of relevant concepts and themes that play a role in the debate about hydrogen.

The structure of this article is as follows. Section 2 sets out the hydrogen project and presents the ten different hydrogen visions that were used in the exercise. Section 3 introduces the repertory grid method, explaining its goal and procedure, and the way in which the method was applied in the project to compare the hydrogen visions. Sections 4 and 5 present the outcomes of the repertory grid analysis. In Section 4 we present the relevant concepts according to the stakeholders, using a frequency analysis. Section 5 presents the outcomes of a HOMALS analysis and discusses the implications of this analysis for the selection of three hydrogen visions. Section 6 wraps up and reflects on the repertory grid method, identifying its strengths and weaknesses, and providing suggestions on how to improve the use of the method in participatory processes.

2. A stakeholder dialogue on the 'hydrogen economy'

The assessment process was set up as a dialogue between policy makers, scientists, NGO representatives and business companies and aims to investigate to what extent, and under which conditions, hydrogen is a viable option for the Netherlands or not, what kinds of governance strategies would be needed to encourage the implementation of hydrogen, and what would be the competence of excellence for the Netherlands in this field. The dialogue does not take a predisposed position towards hydrogen but is designed to be an open process.

In the first phase of the project a range of hydrogen visions had to be identified. This was done on the basis of interviews with sixty companies, government officials

¹ It concerns the project 'H₂ Dialoog' (2004-2008), which it financed by the Netherlands Organisation for Scientific Research (NWO) 'Sustainable Hydrogen' Program, which is part of the larger Research Program Advanced Chemical Technologies for Sustainability (ACTS). For more information see <http://www.nwo.nl/acts> and <http://www.h2dialoog.nl>

and experts in the Netherlands and Belgium, and information of the first National Conference of the Dutch National Sustainable Hydrogen Research program. This resulted in ten different hydrogen visions (see Box 1).

In the second phase of the project, which is the focus of this article, we set up an exercise with the stakeholders in which we used repertory grid to systematically compare the ten hydrogen visions and to structure the ideas stakeholders had with regard to these visions. We expected the grid method to help us to select three hydrogen visions to be explored further in the dialogue project, and to give us insight into the concepts that were considered relevant for the dialogue.

In the third phase of the project we divided the stakeholders up in three groups, which each started to explore the implementation of one of the three hydrogen visions, and to build a 'strongest' case for 'their hydrogen vision'.

In the final phase of the project, the three groups will compare their results and will develop conclusions and recommendations for Dutch energy policy makers.

Box 1: Ten visions on hydrogen (derived from Van de Kerkhof et al., 2005)

Vision 1. All H₂ - Centrally produced from clean fossil: "A brand new network! Let's do it again"

H₂ in the Netherlands is centrally produced from fossil sources (natural gas) with underground CO₂ storage. H₂ is distributed through a heavy H₂-infrastructure. On site (in buildings), it is converted into heat and power through micro-CHP. The national electricity and natural gas infrastructure have become redundant.

Vision 2. Central all electric: "H₂ from fossil sources: it's electrifying!"

Electricity in Europe is centrally produced from fossil sources (natural gas with underground CO₂ storage) and to some extent from nuclear and renewables. Electricity distribution goes through an extended grid. The surplus of electricity is converted into H₂ as reserve. The natural gas grid becomes redundant.

Vision 3. All Electric: Decentralized and renewable: "Many a little makes a mickle"

Electricity is produced at house or neighborhood level from renewable sources, e.g. advanced solar PV with heat/cold storage, and advanced heat exchange systems. The surplus of electricity is converted into H₂. This is used for private car transport. If there is H₂ left, it is stored in a 'light' H₂ network.

Vision 4. Adding H₂ to the natural gas grid: "The Dutch do it their own way"

H₂ is added to the national natural gas grid and is distributed to the households through this existing infrastructure. H₂ from biomass and coal is imported. Because of the mix with natural gas, the H₂ is not necessarily of high quality. As the amount of H₂ in the grid increases, the household appliances and infrastructure are gradually adjusted.

Vision 5. Global H₂ from non fossil sources: "CO₂ is the problem and the solution must be large scale"

Electricity is produced at large scale in Northern Africa and Europe from non fossil sources (large scale solar in the Sahara, offshore wind in the Atlantic Ocean, hydro and nuclear. Where a heavy infrastructure for electricity is not available, H₂ is transported through pipelines and tankers. H₂ is then locally converted into electricity or delivered for transport or micro-CHP.

Vision 6. H₂ for the mobile sector: "It's mobility, you fool!"

Transport uses H₂ combined with fuel cells. The H₂ is carried through pipelines and tankers to fuel stations or is produced on site. There, it is delivered to the consumers. Cars are fully electric and light in weight.

Vision 7. H₂ without fuel cell: "H₂ makes it, fuel cells won't.."

H₂ is used in stationary and mobile applications but without a fuel cell. Instead, H₂ is converted in useful energy through conventional combustion technologies. Hence, the quality demands for H₂ are less which enables a greater variety of sources for the production of H₂.

Vision 8. H₂ Cartridge system: "Clique-claque, over the counter"

H₂ is stored in portable cartridges that can be easily refilled. Small end users, such as households and small companies use them for stationary (like butane gas) and mobile applications. The cartridges are filled at industrial sites or at fuel stations, which enables to use the heat while refilling. Empty cartridges are exchanged.

Vision 9. Recycling of industrial H₂: "From what we now blow into the air, industries can be energized!"

H₂ from industrial activities is used as a secondary source of energy or as a raw material for industrial processes. The H₂-infrastructure is located on industrial sites. The surplus is delivered to other users.

Vision 10. Gasification without H₂: "We do not need H₂ to solve the problems!" (a non-H₂ reference vision)

The focus is on natural gas and biogas, as well as biofuels for the entire energy system. For the production of electricity also renewables and nuclear are used. Innovations in renewable technologies are developed and used at an increasing scale. Through underground CO₂ storage and bio fuels the major problems for the energy system, climate change and security of supply, are solved.

3. Repertory grid to unfold categorizations

Repertory grid has its origins in construct psychology and is mainly used in clinical settings. In these settings, the technique is used as a way of trying to increase the psychologist's understanding of how an individual views the world (Kelly, 1955; Ryle, 1975; Bonarius et al., 1981; Fransella et al., 2004). Since the introduction of the method, it has found its home in the areas of artificial intelligence, education, and human learning. In the field of policy analysis too, this method has gradually gained ground (Dunn and Ginsberg, 1986; Van der Sluijs et al., 2001; Dunn, 2001; Van de Kerkhof, 2004). The basic idea of the technique is that the minds of people are 'construct systems', which reflect their constant efforts to make sense of the world. These construct systems are highly individual in nature and guide people's behavior. People observe, draw conclusions about patterns of cause and effect, and behave according to those conclusions. People's construct systems are not static, but are confirmed or challenged every moment they are conscious. Moreover, construct systems are not always internally consistent. People can, and do, live with a degree of internal inconsistency within their construct system. Basically, repertory grid aims to unfold categorizations by articulating the individual construct systems of people. This helps to better understand what meaning people give to the world around them.

Repertory grid includes two concepts: 'elements' and 'constructs'. The elements are the objects of people's thinking to which they relate their concepts or values. The constructs are the discriminations that people make to describe the elements in their personal, individual world. An essential characteristic of a construct is that it is bipolar. Repertory grid relates the construct of an individual directly to the elements. In the first applications of the repertory grid method, in the field of interpersonal relationships (Fransella, 1977), people that were important for the respondent constituted the elements. Constructs were the qualities used to describe these persons, for instance, 'nice' or 'aggressive'. In the case of the hydrogen dialogue, ten different hydrogen futures constitute the elements, and the constructs are the qualities that are used to distinguish between the future visions, for instance, 'sustainable' and 'not sustainable'.

The repertory grid procedure can best be characterized as a structured interview in which the respondent is confronted with a triad of elements and is then asked to specify some important way in which two of the elements are alike and thereby different from the third (Jankowicz, 2004, see also Fransella et al., 2004). The characteristic that the respondent uses to distinguish between the elements is the construct. Since the construct is bipolar, it can be presented on a scale. After that, the respondent is asked to rate the elements (that are possible/desirable to rate) on the scale that represents the construct, and to indicate which pole of the construct he or she prefers. Then, the interviewer moves on to the next triad of elements. Typically, these steps are repeated until the respondent mentions no new constructs anymore.

Repertory grid is characterized by two claims. The first claim is that the method efficiently, i.e. with a limited number of interviews that cost a limited amount of time, elicits the true range of relevant constructs in a particular context (Dunn, 2001). The second claim is that repertory grid is exceptional compared with many other techniques, as the interviewer, due to his or her minimal role, does not steer the respondents through questioning (Van der Sluijs et al., 2001). It depends on the goal of the exercise whether the elements are chosen by, or in cooperation with,

the respondent, or whether the interviewer chooses the elements. In the case of the latter, the interviewer will conduct a certain degree of steering.

Repertory grid is not the only method that can be used to assess how and which constructs people use or find important in a particular context. Some examples of other methods that can be used are value-focused thinking (Arvai and Gregory, 2003; Gregory et al., 2001; Keeney, 1994), Q Methodology (Brown, 1986; Webler et al., 2001), and Semantic Differential (Osgood, 1957; Heise, 1970). Compared to these alternatives, the advantage of repertory grid for our project is that it enables elicitation of constructs instead of imposing them (this refers to the non-steering claim of the method). The constructs are not determined by the researcher, but by the respondent. Another reason to use repertory grid in the hydrogen dialogue was that this method had been applied in an earlier dialogue project (Van de Kerkhof, 2004) and we were keen on gaining more experience with this method and applying it in a computerized fashion.

Using repertory grid in the hydrogen dialogue

In the hydrogen dialogue, the repertory grid method was used in a group setting by means of a software application. Various software applications for repertory grid exist, such as GridSuite, Omnigrad and Enquire Within. The existing software packages are mostly meant as an aid for the interviewer, not as an interface for the respondent. Moreover, the software packages lacked the features that were necessary for the hydrogen dialogue project. For instance, in GridSuite it was not possible for the interviewer to describe the elements in advance, which was a requirement for the hydrogen dialogue. Therefore, the software packages were used as inspiration for the development of a new software tool, adapted to the specific requirements of the hydrogen dialogue.

The repertory grid method was used during a workshop with 24 participants, representing industry, government, NGO's and knowledge institutes. Each participant conducted a repertory grid analysis on a computer, by following the instructions that appeared on the screen in front of them. The research team was present to support the participants where needed.

The software tool

To make clear to the reader how the repertory grid exercise worked, we will now describe the different steps that the participants took.

In the first screen the participant filled in his/her name and institution. Then an instruction followed, explaining the procedure. After that, the exercise started, in which the participants conducted the repertory grid analysis in several rounds. In each round, the software tool quasi-randomly generated three hydrogen visions (the 'elements' of the repertory grid analysis; see Box 1). Quasi-randomly means that in the first round vision 1 was presented with two random other visions, in the second round vision 2 was presented with two random other visions, et cetera. The reason for this was that we wanted to prevent that some visions were not presented at all, or others very often.

For every triad, the following questions were asked:

1. *Please compare the three visions. In what aspect are two of these three visions similar and do they differ from the third? Please click with your mouse on the two visions that you think are similar.*

This automatically moved the two similar visions to the left side of a five-point scale and the other vision to the right side of that scale visualized on the screen, the scale representing the bipolar construct.

2. A pop-up screen appeared, in which the question was asked: *What kind of characteristic do the two visions share, and what is the characteristic of the third vision?* The remark was made that the two characteristics (the construct) should be bipolar. After that, the pop-up screen closed.
3. *Assign all visions a value on the five-point scale by dragging them with your mouse to a certain position on the scale. The three initial visions can also be moved to other positions. The visions that you think are not possible or desirable to place on the scale can be left aside.*
4. When this part was completed another pop-up screen appeared, asking: *Which of the two characteristics (left side or right side of the scale) do you prefer for the long term?* Then, the pop-up screen closed.
5. *Would you like to distinguish the same three visions again on the basis of a different characteristic, or would you like to continue with the next triad?*
If the participant chose to continue with a new triad, the software tool quasi-randomly generated a new triad.

Traditionally, the elicitation of constructs takes as long as necessary. It stops when the interviewee does not come up with new constructs anymore, assuming that the complete construct system has by then been covered. Due to the group setting, and the computerized way of interviewing, this procedure was not possible for our repertory grid exercise. Therefore, the research team planned one hour for the elicitation of constructs. Participants that indicated to be finished before the end of the hour were allowed to stop.

As mentioned before, we had two purposes with using the repertory grid method. The first was to elicit the whole range of relevant concepts that are considered to be important in the hydrogen debate. The second purpose was to systematically compare the ten hydrogen visions and to select three visions on the basis of the constructs mentioned by the group. These two purposes had important implications for the analysis of the data. Where data analysis of the traditional repertory grid exercises focuses on the grid of the individual, we are more interested in the grids on an aggregated (group) level, since this tells us something about the way in which the group as a whole viewed and clustered the visions. Two types of analyses were conducted: a frequency analysis and a HOMALS analysis.

4. Frequency analysis: Analyzing constructs

As a first step, we determined how many unique constructs the participants had mentioned. We did this by counting the constructs that every participant added. In total, the participants mentioned 171 constructs, which amounts to over seven constructs per participant on average (if a participant mentioned a construct more than one time, we counted this as one construct). Several constructs were mentioned by more than one participant, whether or not in the same wording. Therefore, we decided to categorize the constructs. This means that constructs with a slightly different wording but the same content are placed within one category. Three independent judges conducted this categorization, in order to enlarge the reliability of the categorization. Divergent judgments were solved by means of discussion. In some cases, the categorization of constructs was very easy. For example 'H₂-No H₂' and 'Based on H₂-Possible without H₂' were placed in the same category, because both refer to the role of hydrogen as an energy-carrier in the future energy system.

However, in some cases it was harder to categorize the constructs. For example, 'Households-No households' and 'Mobile applications-Stationary applications' refer to different contexts, but both were placed in the category 'Focus on sector-Focus on system'. Categorizing the constructs resulted in 43 unique construct categories.

As we mentioned before, one of the claims of repertory grid is that it is able to elicit the true range of relevant constructs in a particular context (Dunn, 2001). This claim is based on the use of repertory grid as a face-to-face interview technique, with only one person at the same time. We would like to know whether this claim also holds for the computerized group exercise that we conducted. To find out whether we elicited the true range of relevant constructs with regard to the ten hydrogen visions, we conducted the following frequency analysis. Following an alphabetical order of participants, we calculated how many new constructs every participant added to the list of constructs. For example, if participant A mentioned 5 constructs, we put '5' in participant A's cell of the frequency table. Suppose participant B mentioned 5 constructs, of which participant A already mentioned 2, we put '3' in participant B's cell of the frequency table (since he mentioned 3 new constructs). Figure 1 shows the cumulative number of new constructs. According to the claim that a repertory grid can elicit the true range of concepts it should be visible in this figure that after a certain number of participants no new constructs are added to the list. This means that the line should flatten out.

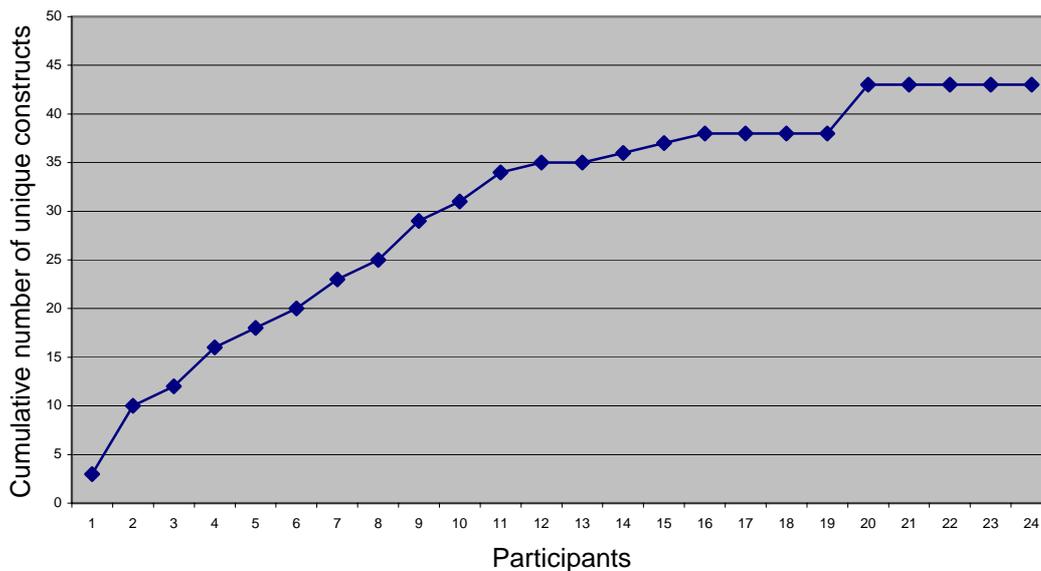


Figure 1 - Frequency analysis: Cumulative number of unique constructs

If we look at Figure 1, it seems indeed that saturation has been reached. After 16 participants the line starts flattening out, then participant 20 mentions 5 new constructs, and then it flattens out again. Seemingly, we elicited all constructs that this group of participants applies to make sense of the ten hydrogen visions. But what then are these constructs? Table 1 shows the list of constructs, sorted on decreasing order of frequency.

Table 1 The 43 unique construct-categories

Nr.	Number of people who mentioned the construct	Construct label <i>Between brackets: number of participants who preferred this side of the construct</i>
1	17	H ₂ (16) – no H ₂ (1)
2	14	New infrastructure(6) – Existing infrastructure(8)
3	12	Short term solution(3) – Long term solution(9)
4	12	Central(3) – Local(9)
5	11	Focus on sector (6)– Focus on system(5)
6	10	Flow(8) – Batch(2)
7	9	Existing technology(4) – New technology(5)
8	8	Fossil(3) – Non-fossil(5)
9	7	H ₂ as energy-carrier(2) – Electricity as energy-carrier(5)
10	7	Existing system(2) - New system(5)
11	6	Small scale(4) – Large scale(2)
12	6	With fuel cell(5) – Without fuel cell(1)
13	6	Sustainable(6) - Not sustainable(0)
14	6	Many advantages for the environment(6) - Few advantages for the environment(0)
15	5	National(2) – International(3)
16	4	Partial solution(0) - Total solution(4)
17	3	CO ₂ storage(1) – No CO ₂ storage(2)
18	3	H ₂ infrastructure(1) - Electricity infrastructure(2)
19	3	H ₂ as buffer(2) – H ₂ as carrier(1)
20	3	High cost(1) – Low cost(2)
21	2	Electricity as energy-carrier(0) – Natural gas as energy-carrier(2)
22	2	Plausible(2) – Not plausible(0)
23	2	Same market(0) – New markets possible(2)
24	2	Energy mix(2) – No energy mix(0)
25	1	H ₂ use(0) - H ₂ production(1)
26	1	Possible(1) – Impractical(0)
27	1	Network technologies(1) – Conversion technologies(0)
28	1	Fuel specified(0) – Fuel not specified(1)
29	1	Sources not mentioned(0) – Sources are local and sustainable(1)
30	1	Continuous supply possible(1) – Discontinuous supply(0)
31	1	Energy in liquid phase(1) – Energy only electric(0)
32	1	Energy mix(1) – Based on electricity(0)
33	1	Use of Dutch natural gas(1) – No use of Dutch natural gas(0)
34	1	Partial overlap H ₂ (1) – No role H ₂ (0)
35	1	No goal(0) – Goal(1)
36	1	No large growth H ₂ (0)– Increase H ₂ applications(1)
37	1	H ₂ with possibility other appliances(1) - H ₂ without other appliances(0)
38	1	With PV (photovoltaic)(1) – Without PV(0)
39	1	Underground infrastructure needed(1) – No underground infrastructure needed(0)
40	1	Solution(1) – No solution(0)
41	1	Retail H ₂ (1)– No retail H ₂ (0)
42	1	Power surplus in H ₂ (0)– No power surplus in H ₂ (1)
43	1	Question marks safety with public(0) – Acceptation without problems(1)

By far the most mentioned construct was 'H₂ - no H₂'. Most of the high frequency (>7) constructs follow directly from the description of the construct. For example, the poles of the construct 'New infrastructure' or 'existing infrastructure' are characteristics that are in most cases explicitly stated in the description of the vision (see Box 1). Also striking is that the majority of constructs was mentioned by less than 5 participants. This implies that 'making sense of hydrogen' takes place on the basis of different constructs for different people. This underlines the basic assumption of the repertory grid technique that construct systems are highly individual in nature. Moreover, it underlines the importance of non-steering methods to elicit people's ideas.

Note that repertory grid is not an attitude-measurement. Preferences within constructs cannot directly be translated to (components of) attitudes. Nevertheless, the grid analysis reveals findings that are important for the reduction of ten to three visions. If we want to identify three divergent visions, table 1 can help us by delivering insights on which constructs are distinguishing for most participants. For example, it appears from construct 3 that many participants think it is important to distinguish between long-term and short-term solutions. The repertory grid outcomes reveal that most participants favor visions that concern long-term solutions, rather than visions that present short-term solutions. This would plead for framing the short-term solutions (e.g. visions 4, mixing H₂ in the natural gas network and 9, recycling of industrial H₂) in a longer-term scope.

This frequency analysis gives us insight into the constructs and the saturation of the analysis of the constructs within the group of participants. However, to be able to reduce the ten hydrogen visions to three, we need an additional analysis that can give us insight into how the elements (the hydrogen visions) relate to each other and to the constructs. The following section explains this analysis.

5. HOMALS: Analyzing elements

HOMALS is an acronym for 'HOMogeneity Analysis by means of Alternating Least Squares'. HOMALS reduces the dimensionality of data, without ignoring underlying relations. This means that, when conducting a HOMALS on the future hydrogen visions, visions that have been evaluated in a similar way by the participants are placed close to each other, while visions that have been evaluated in a different way are placed far apart.

In order to do this, HOMALS tries to divide the visions in homogeneous subsets for every variable. The variables are the ratings of the visions by the participants on the constructs. For instance, variable 1 is the rating of the visions by participant 1 on construct 1, variable 2 the rating of the visions by participant 2 on construct 1, variable 3 the rating of the visions by participant 3 on construct 1, etcetera.² The matrix that is used for this analysis contains the ten visions in the rows and 251 variables in the columns. Based on these homogeneous subsets per variable, the relations between the visions are represented in a two-dimensional plot (figure 2 is a simplified example of this two-dimensional plot).

² Construct 1' means 'first mentioned construct' (note that the first construct participant 1 mentioned is very likely not the same as the first construct mentioned by participant 2). Since each variable is a participants rating of the ten visions on a construct, each variable consists of 10 levels.

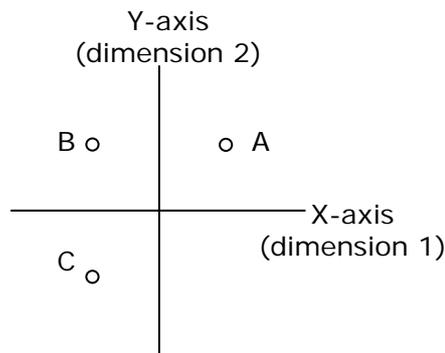


Figure 2 - The two-dimensional plot in which HOMALS summarizes results

The two axes (dimensions) can be interpreted as 'meta-constructs' or 'higher-level' constructs, covering the constructs mentioned by the participants. The meaning of the X-axis in the figure can be interpreted by looking at the visions that are at the right side and the left side of the Y-axis respectively. After all, vision A in figure 2 is the opposite of visions B with respect to the characteristic that is represented by the X-axis. The meaning of the Y-axis can be interpreted in a similar way by looking at the visions that are above and under the X-axis respectively. Vision B in figure 2 is the opposite of vision C with respect to the characteristic that is represented by the Y-axis. One can check the interpretation of the axes (dimensions) by looking at the data on an individual level. One of the items in the output of the HOMALS analysis is a table that shows for every variable the discrimination measures on both dimensions. The discrimination measure indicates to what extent that variable 'scores high' on (and hence is described by) each of the dimensions. To check whether the interpretation of the X-axis (dimension 1) is plausible, one should look for a variable with high discrimination measure on dimension 1 and a low discrimination measure on dimension 2. If the construct represented by this variable fits with the interpretation made before, then this supports the interpretation. This should be repeated to get a good idea about the amount of support for the interpretation.

Not the construct-categories that are tabulated above (Table 1), but the original constructs as mentioned by the participants are used for the HOMALS analysis, since these give more detailed information.

Figure 3 shows the resulting two-dimensional plot for the HOMALS analysis on visions 1 to 9. Note that vision 10 was not included in the analysis. The plot that resulted from the HOMALS analysis including all ten visions appeared very difficult to interpret. Vision 10 was an outlier in that plot. Repeating the analysis without the outlier resulted in the plot below that was easier to interpret. The fact that vision 10 was an outlier indicates that stakeholders evaluate vision 10 differently from the rest of the visions.³

³ Because of the deviant character of vision 10, the project team decided to include vision 10 in the dialogue. The three dialogue groups, irrespective of their starting point vision, includes vision 10 as a reference vision in their analysis.

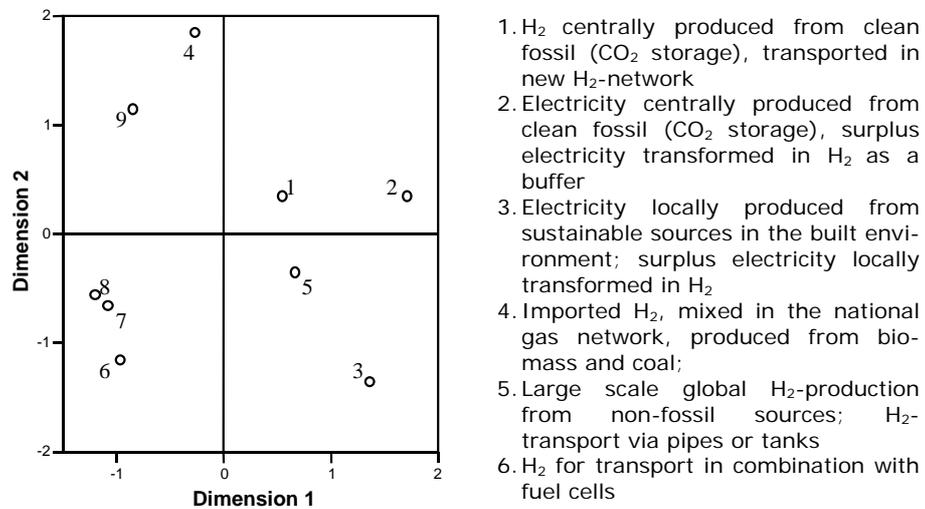


Figure 3 - Vision 1 to 9 plotted in a two-dimensional figure (object scores)

Three things are important to keep in mind when interpreting the plot. Firstly, the axes can, in principal, be rotated around the origin. This implies that examining the distances between the visions in figure 3 might facilitate the interpretation of the results (in addition to examining the distances between the visions and the axes). The distances between the visions indicate the convergence and divergence of visions. Secondly, visions that are far from the origin are more interesting in the light of the project, because these visions have a high level of a certain characteristic and are therefore more salient. Thirdly, one should note that positive or negative values in the figure do not correspond with positive or negative evaluation. A positive and a negative value on either dimension can be interpreted as two opposites on the scale of a bipolar meta-construct.

The visions are fairly equally distributed among the four quadrants of the figure. Visions 6, 7 and 8 seem to form a cluster, and visions 4 and 9. For the other visions the clustering is less clear. We will start the interpretation of the figure by examining the axes. We developed a few interpretations.

The X-axis

The X-axis can be interpreted by comparing the visions that are at the right side of the Y-axis to the visions that are at the left side of the Y-axis. The visions at the right side of the Y-axis have something in common which distinguishes them from the visions at the left side of the Y-axis, and vice versa. First we examine the visions at the left side of the Y-axis. In vision 4, H₂ is mixed in the natural gas network. Vision 9 concerns the recycling of industrial H₂. Vision 6 describes the use of H₂ for transport applications. Vision 7 describes how H₂ is being transformed in energy by means of conventional combustion technologies for stationary and mobile applications. Finally, vision 8 concerns the H₂ cartridge system. What these visions seem to have in common is that they all describe partial solutions or incremental changes. Let's have a look to see whether this is the characteristic that distin-

guishes these visions from the visions at the right side of the Y-axis. Vision 1 concerns the central production of hydrogen from clean fossil sources (CO₂ storage). In this vision the national electricity and natural gas infrastructure have become needless. H₂ is transported by means of a new H₂-infrastructure. Vision 2 describes an all-electric system, in which electricity is produced centrally from clean fossil, nuclear and sustainable sources. Hydrogen is being used as a buffer. Also in this vision that natural gas infrastructure has become needless. Vision 3 concerns the local production of electricity from sustainable sources in the built environment. This is also an all-electric vision, in which H₂ is being used as a fuel for cars. In vision 5 H₂ is being produced from non-fossil sources at a global scale. To conclude, the visions at the right side of the Y-axis can all be interpreted as system changes. Dimension 1 (X-axis) might thus be incremental change versus system change. The constructs that have high discrimination measures on dimension 1, and low discrimination measures on dimension 2 can be examined to check whether this interpretation makes sense.

Discrimination measures range from 0 to 1. We choose to examine discrimination measures higher than 0.9 as high scores, and lower than 0.1 as low scores.

Participant 14 scores .990 on dimension 1 and 0.080 on dimension 2 for his construct 7. This construct is 'partial solution – total solution'. Person 22 scores .921 on dimension 1 and .024 on dimension 2 for his fourth construct. This construct is 'partial solution – total solution'. These two constructs support our interpretation of dimension 1. Participant 8 scores 0.954 on dimension 1 and 0.08 on dimension 2 for his eighth construct. This construct is 'H₂ infrastructure – Electricity infrastructure'. This construct is less obvious than the other two in supporting or rejecting our interpretation of dimension 1. It might be that this person thinks of a H₂ infrastructure as a system change, and of an electricity infrastructure as a incremental change. However, we cannot tell this from the data, so no hard conclusions can be drawn.

The Y-axis

The Y-axis can be interpreted in a similar way. Visions 9, 4, 1 and 2 are above the X-axis. Vision 9 describes the industrial recycling of H₂. In vision 4, H₂ is mixed in the natural gas network. Vision 1 concerns an all-H₂ energy system, in which H₂ is produced centrally from clean fossil sources. Vision 2 is the all-electric vision, in which electricity is produced from clean fossil, and in which H₂ serves as a buffer. In none of these visions sustainable sources are being used; the visions are based on fossil sources (only vision 9 is deviant in that H₂ is a rest product from industrial activities). The visions that are under the X-axis are not based on fossil sources, or do not explicitly mention the type of sources (visions 6, 7 and 8). Visions 3 (all-electric vision in which electricity is produced locally) and vision 5 (global H₂-production) describe the use of sustainable sources. Vision 6 describes the use of H₂ for transport, vision 7 the use of H₂ for stationary and mobile application without the fuel cell, and vision 8 is the cartridge system. The distinction between the visions above and under the X-axis is not very obvious. Examining the discrimination measures might help the interpretation.

Due to a lack of participants that have discrimination measures higher than 0.9 on dimension 2 and lower than 0.1 for dimension 1, we examine discrimination measures higher than 0.7 on dimension 2 (and lower than 0.1 on dimension 1).

Participant 17 scores .841 on dimension 2 and .087 on dimension 1 for his seventh construct. This construct is 'existing system – new system'. Participant 15 scores 0.853 on dimension 2 and 0.079 on dimension 1 for his seventh construct. This construct is 'sustainable – not sustainable'. Participant 21 scores .707 on dimension

2 and 0.085 on dimension 1. This construct is 'short-term solution – long-term solution'.

These three constructs more or less support the interpretation of dimension 2 as 'use of fossil sources versus no use of fossil sources'. The dimension might also be interpreted as 'based on the current system (above the X-axis) versus a new energy-system (under the X-axis)'. This interpretation might actually be a higher-level interpretation of the former interpretation (fossil-not fossil). After all, the current energy-system is based on fossil sources, and an energy-system based on non-fossil sources would imply a new energy-system. If we relate the construct of participant 21 to this (short-term solution versus long-term solution), the sound answer would be that 'based on the current system' corresponds to short-term solutions, whereas 'a new energy-system' corresponds to long-term solutions.

Note that the interpretations we just gave are very similar: dimension 1 was interpreted as 'incremental change versus system change' and dimension 2 was interpreted as 'based on current system versus new system'. Examining the four quadrants might give some additional information.

Remarkably, these quadrants correspond to a large extent with the sectors in economy. In the upper left quadrant the sector industry in combination with gas sector is located. The transport sector is located in the lower left quadrant, while the energy sector (gas and electricity) can be found in the upper right quadrant. The lower right quadrant can be associated with the built environment. Of course there are connections between these quadrants and sectors. This observation is possibly of interest because of the fact that the operation of sectors takes place from various centres and on various levels of scale. The upper right quadrant and the upper left quadrant operate on a super-national level, by international (European) legislation and by international (transport) industry respectively. The upper left quadrant (industry and gas) operates, at least partly, on a national level (investment facilities, accessibility), while the lower right quadrant (built environment) operates mainly on national and sub-national level. Figure 3 thus seems to indicate also an institutional distinction between potential H₂-visions.

The aim of the Repertory Grid exercise was to find out which visions converge and diverge in the eyes of the stakeholders, to be able to formulate three divergent visions that serve as starting points for the three dialogue-groups.

Figure 1 gives an idea about the convergence and divergence of the visions. Divergent visions are positioned far from each other, while convergent visions are positioned close to each other.

Vision 4 and 9, positioned in the upper left quadrant, are both visions that elaborate as long as possible on the current system and current infrastructure. Vision 4 concerns mixing the H₂ in the natural gas network and vision 9 is the industrial recycling of H₂. Many participants consider these visions as transition visions, heading for structural long-term solutions. Table 1 showed that more participants prefer visions that give long-term solutions instead of short-term solutions than vice versa. This would be a reason not to select vision 4 for the Hydrogen Dialogue, but to use this vision as a transitional stage to another vision, e.g. vision 1 (central H₂-production from clean fossil).

Visions 6, 7 and 8, positioned closely to each other in the lower left quadrant, are partial solutions: visions in which H₂ is not integrated completely in the energy-system. Vision 6 concerns H₂ in the transport sector, vision 7 concerns H₂ for mobile and stationary applications without the use of the fuel cell technology, and vision 8 is the cartridge vision. With regard to vision 8, the frequency analysis seems to indicate that some participants do not prefer a batch infrastructure (cartridges), but a flow infrastructure (2 participants prefer batch and 8 prefer flow infrastructure). Vision 6 can be selected for the dialogue, since many participants have

shown to be interested in visions that focus on a certain sector, and in the question to what extent these sectors can contribute to a broader introduction of H₂ in the energy system. Though, one has to bear in mind that The Netherlands does not have a (passenger) car industry, as a result of which the possibilities of control will be limited. This would plead for an international orientation.

Vision 2 is an all-electric vision in which H₂ has a buffer-function. The participants have various opinions about the extent to which there will be surplus electricity, because gas and coal plants are in principle controllable. This means that it is doubtful to what extent this vision can lead to an important role for H₂ in the energy system on the long term.

Vision 3 is a sustainable electricity vision with a local production of electricity and H₂ as a buffer. According to this vision, the production and use of H₂ starts on a small scale level in the built environment. During the workshop, some participants wondered whether this system of 'distributed generation' will be sufficient if the transport sector will use H₂ as well. What is interesting about this vision, is that, because of the local character of the built environment, this vision probably offers more possibilities of control for the Dutch government than visions that focus on other sectors like energy, transport and industry.

Based on the analyses and these considerations, three H₂-visions are formulated that will serve as a starting point for three respective dialogue groups:

1. *Central 'all H₂' from clean fossil*: The transition vision is that H₂ is being mixed in the natural gas network (vision 4) and is transported via the existing gas infrastructure to the households. If necessary, H₂ from biomass and coals is imported. Also, H₂ is being produced on-site in industrial activities (vision 9). The final future vision is based on vision 1, and has to be worked out by the dialogue group. An important issue of discussion for this group will be to determine whether such a transition path offers opportunities for system innovation, or whether it, as some people think, obstruct system innovation.
2. *H₂ in the transport sector*: Hydrogen is being introduced in the transport sector, combined with fuel cells or other conversion technologies. H₂ is being transported via pipes and tankers to filling stations, from where it will be supplied to consumers (vision 6). The final future vision can also be vision 1, 2 or 5. Important issues for discussion will be to what extent the transport sector can be a driving force for an integrated H₂-system. And, if doubts about this exist, how can this internationally organized sector be controlled on a societal level?
3. *Sustainable and local*: H₂ is initially being produced on a small-scale level, locally, and is being used in the built environment. Advanced Photovoltaic systems are being used, as well as underground heat/cold storage and heat/cold recovery systems. Surplus electricity is transformed on the spot in H₂, which can be used as a car fuel. The remainder can be stored in what will become a light (local) H₂-network (vision 3). Important issues for the discussion will be: Does central production deliver enough H₂? Is this already a final future vision, or is a final future vision something like a globally organized energy system as described by vision 5? What are the driving forces for this vision?

6. Reflection on the repertory grid method

Reflection on the procedure

This exercise has shown that a computerized repertory grid is able to elicit the constructs participants use to make sense of a particular issue, even if the exercise takes place on a group level. Furthermore, participants find it in general fun to do. The frequency analysis showed that the elicitation of constructs had reached saturation, which means that during the exercise probably all relevant constructs of these stakeholders with regard to the ten hydrogen visions have been identified. A disadvantage of a software application is that there is less control. For instance, a lot of non-bipolar constructs have been mentioned by participants; in a face-to-face interview this could have been clarified and prevented. Moreover, in a face-to-face interview the interviewer can check with the interviewee whether two constructs that seem similar to the interviewer are equal or not. This could have helped the categorization of constructs in this exercise. As mentioned before, in some cases it appeared difficult to categorize a certain construct. Plausibly, mistakes have been made. The possibility of checking the exact contents or meaning of constructs can prevent this.

A critical notion can be made about the elements that were used in the exercise. In the early applications of the Repertory Grid Technique elements were e.g. persons. One can imagine how the name of a person important to someone activates an image by activating a network of associations. The question is whether the visions that were used as elements were able to activate a similar network. As appeared from the frequency analysis, the constructs that were mentioned most often were obvious constructs that followed directly from the description of the vision. This would mean that what we put in came out. A reason for this might be that the descriptions of the visions were too difficult, or too long. Probably a picture, or a short movie can better activate an associative network than some lines of text. A second reason for this might be that these stakeholders do not have such an associative network structure in their heads (yet) that they use to give meaning to potential future energy systems. An associative network is based on experience (Smith & DeCoster, 2000); maybe such a network cannot exist without experience. This would plead for not applying Repertory Grid on hypothetical or future situations (elements), because people simply cannot have experience with these situations.

Reflection on the possibilities of analysis

The goal of the analysis was to be able to select three future visions that are maximally divergent according to the stakeholders. In principal, the analysis is suited for this. However, it is not possible to know in advance how many clusters of elements will be found, or how many divergent elements can be chosen. For a next time, it might be decided to make the amount to which the visions had to be reduced dependent on the results of the analysis.

Compared to the analysis of an individual repertory grid exercise, a group exercise requires quite some interpretations from the researchers. In our analyses, interpretations were needed in order to categorize the constructs for the frequency analysis and to interpret the HOMALS plot. The reliability of the categorization for the frequency analysis was enhanced by having three judges do the categorization. The interpretation of the HOMALS plot was done by means of discussion within the research team.

We drew conclusions about the divergence of visions on the basis of the collective grid and decided that a divergent vision is a vision that is positioned far from the other visions in the plot that resulted from the HOMALS analysis ('between-visions divergence'). However, a divergent vision can also be defined as a vision that is being evaluated divergently by different stakeholders ('within-visions divergence'). HOMALS is not suited to analyze this type of divergence.

HOMALS is suited for the analysis of the question how the visions are related to each other, based on the participants' evaluation of the visions by the constructs they mentioned. A similar analysis of the question how the participants or the constructs are related to each other is not very well possible, because all participants mentioned different constructs. Due to this, a matrix with participants or constructs in the rows (instead of visions) has too many missing values. A HOMALS for the participants can for instance only be done when only the most frequently mentioned constructs are taken into account, which are only five (this is also true for other analyses that calculate distances within variables, e.g. cluster analysis).

Reflection on the use of the technique in a general (policy) context

Repertory grid proves to be a relatively quick method to elicit the relevant concepts with regard to an issue. All data is produced "bottom-up", in contrast to e.g. surveys in which the elements and often also the answering possibilities are imposed by the researcher. The data showed that this bottom-up approach is very valuable, since constructs appear to be very individual (remember that the majority of (categorized) constructs was mentioned by less than 5 participants).

The exercise is not only helpful for the researcher, but also for the participant since it stimulates people to structure their thoughts without giving them difficult tasks. As such, the method can enhance learning on an individual level. But also on a group level the method can be applied to enhance learning. This depends on the procedure that's being followed in the application of the method. For instance, a triad is presented to the whole group of participants. Then a facilitator asks each of the participants in the group to give his constructs with regard to that triad, but only the ones that were not mentioned by other participants before. This stimulates the participants to be creative and to come with new constructs, ones that they wouldn't have thought of if they had done the exercise individually. As such, it can serve as a starting point for a dialogue in which one aims for structuring a complex problem. Another application of the method is as a measurement for learning over time. Doing a repertory grid at the start of a process as well as at the end allows on to investigate how ideas and construct systems have changed over time, and hence whether learning has taken place.

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