“Assessment of the potential, the actors and relevant business cases for large scale and seasonal storage of renewable electricity by hydrogen underground storage in Europe”

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Executive Summary

Recently, the European Commission has set the 20-20-20 target (20% GHG emission reduction versus 2005, 20% renewable energy share, 20% energy efficiency increase). Because of this, a more strongly fluctuating energy supply will be very likely, causing the need for energy storage. This will confront society with emerging technologies that are unknown to most lay people (1). One of the possibilities for energy storage is underground hydrogen storage, studied in the Hyunder project, of which this study is a small part. How the public will view hydrogen storage could be of crucial influence on its’ implementation. This study is to our knowledge the first investigation of lay people’s beliefs of and associations with hydrogen storage.

Previous research and experience have shown that the public can have very different views and concerns about these issues than experts, and a lack of attention to this has caused major problems in other energy projects, such as wind energy projects or CO_2 storage projects (2,3). Currently, little to nothing is known regarding public perception of energy storage, specifically regarding hydrogen storage. There are also some methodological challenges to quantitatively studying public perception of something that is most likely unknown to most of the public. Therefore a more elaborate first exploration of lay people beliefs regarding hydrogen storage and associated topics with qualitative methods seemed warranted. The current study used the mental model approach with 16 in-depth interviews conducted in the Netherlands using a rather open interview protocol, eliciting public beliefs and perceptions by allowing interviewees to express their beliefs and perceptions of hydrogen storage and associated topics freely without being influenced.

Results showed, as expected, that people were rather unaware of the option of hydrogen storage. In general, people were not familiar with energy sources and the energy transition overall. Although most people had heard of hydrogen and had some associations, not many were correct and only few people fully understood the possibilities of hydrogen as energy carrier. None of the people had heard of hydrogen storage, or understood the necessity of energy storage to ensure reliability of energy supply when implementing a higher share of renewables in the energy mix. Many mentioned the association with chemistry in general, and several people knew that it can be used as fuel. Due to the association with water (the Dutch word for hydrogen is “waterstof”), many misconceptions came to light about the aspects of hydrogen. Therefore few people mentioned a risk of explosion, but also few people understood the possible use of hydrogen. People had a very hard time imagining why

one would want to store hydrogen. Most mentioned was the association with gas stations, so the use of storage was to have it available for transport. There was a severe lack of understanding regarding the possibilities of hydrogen as energy storage option for surplus renewable energy. Practically everyone lacked the knowledge to understand the whole chain of reasoning; from the need to increase use of renewables, to the problem of intermittent energy supply by renewables, to the need to store energy, to hydrogen being a possibility for this, to how to produce hydrogen, etcetera. After people were given information on this reasoning, they were mostly quite enthusiastic. However, this conclusion should be nuanced by the fact that most interviewees had a hard time envisioning any other options for our future energy system, and also by most interviewees’ perception of having too little information to form an opinion on hydrogen storage. The results should be interpreted carefully in general, as this was a first exploratory study based on 16 in-depth interviews, which means that although the whole possible range of beliefs and associations has likely been uncovered, one cannot draw statistically sound conclusions about the amount of people with similar beliefs and associations in the population. Also, the beliefs and associations found in this study are more likely to be representative of the Dutch general populations’ beliefs and associations than of those of local stakeholders, or of other nations. Locally, many other factors such as process management influence public perception of a project

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1 Introduction to the report

1.1 Description of deliverable

This report is one of the deliverables of the EU project HyUnder on large-scale underground storage of hydrogen. The report is rather different from all other reports of the project. Whereas the other reports focus on technical aspects and economics, this report looks at social aspects and for the first time explores public perception of underground hydrogen storage. This is a crucial activity as public perception plays an important role in the public acceptance of energy technologies and underground activities and therefore their deployment.

1.2 Introduction and background of the study

Three key factors are driving the move towards renewable energies: (a) the climate problem, (b) the insight of depletion of fossil fuels and nuclear primary energy sources and (c) the concurrent rise in energy consumption, in particular in emerging economies. All these challenges have been answered at European policy level. By decision of the European Commission, the 20-20-20 target (20% GHG emission reduction versus 2005, 20% renewable energy share, 20% energy efficiency increase) has set the necessary framework for 2020. This targeted increase in renewable energy share will enforce the introduction of a strongly fluctuating energy supply, causing the need for energy storage. This will confront society with emerging technologies that are unknown to most lay people (1). How the public will view these technologies can be of crucial influence on the implementation of these technologies. Previous research and experience have shown that the public can have very different views and concerns about these issues than experts, and a lack of attention to this has caused major problems in other energy projects (2,3). Specifically in the case of storage, such as CCS, whole projects have been cancelled due to public protest (4). Currently, little to nothing is known regarding public perception of energy storage, specifically regarding hydrogen storage. Therefore part of the HyUnder project, a project aiming at mapping out the relevance of hydrogen underground storage, was to initiate a first exploratory study into public perception of hydrogen storage.

There are some methodological challenges to studying public perception of something that is most likely unknown to most of the public. Earlier research shows that a significant part of respondents to surveys does not refrain from giving their opinion, but responds with “pseudo-

opinions”[i1] or “non-attitudes” (5,6). These sorts of “uninformed opinions” have been shown to be unstable and easily changed by contextual information, and can therefore not be seen as predictive of actual public opinion once the public is confronted with plans for actual projects (6, 7, 8, 9, 10). Furthermore, these sorts of opinions would not be a reliable basis to support communication efforts. One of the ways to tackle this issue is to give people information before asking for their opinion. However, earlier studies also show that even with very reliable, valid and understandable information from experts on energy options, people base only part of their opinion on this information from experts (9). Apparently, other beliefs play a significant role as well. Several studies indeed find that lay people can have ideas and beliefs about energy options which are generally not addressed by experts and which sometimes are factually inaccurate (11, 12, 13, 14). For a first study on public perception of hydrogen storage, a more elaborate exploration of lay people beliefs regarding this and associated topics with qualitative methods therefore seemed warranted. The current study used the mental model approach with in-depth interviews using a rather open interview protocol, eliciting public beliefs and perceptions by allowing interviewees to express their beliefs and perceptions of hydrogen storage and associated topics freely without being influenced.

1.3 Objective(s) of the report

Currently, little to nothing is known regarding public perception of energy storage, specifically regarding hydrogen storage. Therefore part of the HyUnder project, a project aiming at mapping out the relevance of hydrogen underground storage, was to initiate a first exploratory study into public perception of hydrogen storage. The current study uses the mental model approach with in-depth interviews using a rather open interview protocol, eliciting public beliefs and perceptions by allowing interviewees to express their beliefs and perceptions of hydrogen storage and associated topics freely without being influenced. The objective is to investigate the whole possible range of beliefs and associations in the Dutch general population. The objective of the current study is not to investigate the amount of people with similar beliefs and associations in the population, this would be the next step and would require a much larger study using a representative sample.

[1] Several studies show that a significant percentage of people are inclined to give their opinion about a topic even if they have little or no knowledge of the topic; for instance, Daamen et al (2006) showed that up to 60% of respondents that had just stated to know nothing about a certain CCS technology did give their opinion of this technology in the next question, even though it had been made very easy to refrain from evaluation.

2 Methodology

2.1 In-depth interviews

The type of beliefs about hydrogen storage held by lay people were measured with in-depth interviews. To include relevant beliefs commonly held by lay people, 16 in-depth interviews were held with people with no professional involvement with hydrogen, climate or energy. Previous studies have shown 16 interviews are sufficient to elicit most commonly held beliefs as the emergence of new beliefs is negligible after 16 interviewees (12).

2.2 Sample

The sample consisted of eight women and eight men ranging from 20 to 56 years of age, with different educational levels. None of the interviewees worked in the field of energy or chemistry or had an education in these fields. All the interviewees lived in the Northwest of the Netherlands.

2.3 Procedure (protocol)

The interviews were held at the ECN office in Amsterdam. The interviewer started each interview with introducing himself and the secretary; the secretary took notes and was not involved in the interview in any way. Next, the subject of the interview was explained by the interviewer, together with the statement that there could be no wrong answers. The interviews were conducted using a very open protocol which allowed respondents to express their beliefs about these topics freely and only be prompted with general questions after a topic was exhausted. There was no fixed list of questions. The interviewer did have the interview protocol as back-up, which contained possible prompts to guide the interview only to the extent that certain topics had to be discussed. Respondents did not receive any information other than planned at specific points in the interview (see below), nor were they corrected during the interview if they expressed factually erroneous beliefs. The order of topics in the interviews was not exactly the same in each interview, with a few exceptions; beliefs regarding hydrogen were elicited before beliefs regarding hydrogen storage. The latter beliefs were elicited after information was given about hydrogen and before information was given about hydrogen storage; these beliefs were asked about again after information about hydrogen storage was given.

At least all the following topics were discussed during the interview, here in the most prevalent order:

- Awareness of energy sources in the Netherlands
- Perceived energy mix, current and future, and consequences thereof
- Hydrogen associations
- Hydrogen storage awareness, associations, understanding
- Questions interviewees had regarding hydrogen storage
- Reaction to information hydrogen storage
- Evaluations of hydrogen and hydrogen storage
- Related associations
- Climate change associations

Two pieces of information were given during the interview, the first after hydrogen associations, before hydrogen storage associations; the second after the hydrogen storage associations: (information was in Dutch, the English translation is reported here)

1. “Hydrogen or H2 is a gas that can be used as a fuel. It occurs naturally in very small amounts, but larger amounts can be made. This does require energy.”

2. The air in the atmosphere around earth consists of various gasses, amongst others nitrogen, oxygen, and carbon dioxide. Carbon dioxide or CO_2 is referred to as a greenhouse gas. Greenhouse gasses in our atmosphere make sure that the warmth that the earth receives from the sun does not escape immediately back to space. This so called greenhouse effect ensures a livable climate on earthy. However, with the use of fuel such as oil, gas and coal, extra CO_2 is released into our atmosphere. This causes the greenhouse effect to increase. The increased greenhouse effect leads to an increase of the average temperature on earth.

   One way to reduce the emission of CO_2 is by making use of energy from wind or solar radiation. This does not ensure energy constantly, as sometimes the wind does not blow or the sun does not shine. To still have energy available during these moments, it is necessary to store surplus energy: when the wind blows hard or the sunshine is particularly strong. Energy from wind and sun is mostly harvested in the form of electricity with the help of wind turbines and solar panels. Electricity is hard to store in large quantities though. One way to store this energy is by using the electricity for the production of hydrogen. Hydrogen is a gas and can easily be stored underground in large quantities.

After interviews were held, interviewees could choose between 25 euro’s in cash or 25 euro’s wired to a charity of their choosing. Both options occurred. If interviewees wanted to know more, some indication on where to find information about energy transition and the use of hydrogen was given. A few weeks later, all interviewees received a summary with some information on the project, on hydrogen storage and on the results of the interviews.

2.4 Analysis

The results were analysed in several ways. First, topical analysis was done by classifying the interview answers per topic. These topics were based on the topics in the protocol and topics were added based on the answers in the interviews. Furthermore, content analysis as well as in-depth analysis was done per interview. This inter alia adds to the understanding of the relations between individual beliefs and associations. A lot of care was taken to keep the analysis as bottom up as possible by staying on the level of literal interview quotes when possible. Although the amount of specific answers within a topic were counted during the analyses, this is not reflected in the results section of this report. This is a conscious decision aimed at avoiding the possible illusion of quantitative results as the design of this study does not support such an interpretation of the data. The study aims at the range of possible beliefs and associations, not the prevalence within the population. To be able to draw conclusions on the latter would require a design with a representative sample of the population, a sample much closer to a 1000 respondents than to 16. The results section therefore stays with qualitative expressions such as “a few interviewees”, or “the majority of interviewees”.

3 Results

3.1 Energy supply

Awareness of energy sources in the Netherlands

The results for this question were obtained by letting people recall all possible energy sources they could think off. They were then asked to narrow it down by naming the energy sources that the Netherlands use to provide for the energy demand for one year. The interviewer would draw an empty glass on a piece of paper and people were asked to draw the proportions of earlier mentioned sources in the drawn glass. The glass represented the 100 % energy demand us of the Netherlands in the period of a year. People had a lot of misperceptions about the energy sources of the Netherlands. Most of them did come up with the most common energy sources (“I think mostly from power plants, natural gas. A small percentage for wind and solar energy”). Coal was hardly mentioned though, and the percentages for the separate renewable sources, like solar, wind and biomass were consistently overrated (“20% Sun, 20% Wind, 30% Oil, 30% Gas”). Overall, there seemed to be a severe underestimation of percentage of fossil fuels in the energy mix. This is in line with results from other Dutch studies on this topic using representative samples (13,15). Only one respondent estimated 80-90% coming from fossil fuels. Furthermore, there were misconceptions about the energy sources themselves. Some of the participants were not able to name any energy source. Sometimes energy was confused with electricity (“I do not even know how light is generated”). Gas reserves in Groningen were a commonly known source though.

Consequences of perceived current energy mix

A remarkable result was the most heard comment: there are no advantages to our present energy sources mix (“I only see disadvantages, when 80% is oil. The big oil producers still have a lot of power”). There was a surprised reaction to the question what the interviewee thought the advantages of the current energy mix are; people found it difficult to think of advantages. Some people did state to find the present energy delivery stable and some stated that the growing influence of renewable sources is an advantage. The question about the disadvantages was received with a lot less surprise and people were much faster in answering. A lot of the disadvantages mentioned were related to the use of fossil fuels. A few interviewees mentioned the finiteness in combination with pollution as the biggest disadvantages. According to some interviewees, renewable sources were not stable enough

and the energy sources mix was not renewable enough (“It’s not renewable. We still buy polluting energy”).

Future of the energy mix in the Netherlands.

The interviewees were further asked what their expectations were of the energy mix in the future. Most people expected the sources to change from fossil fuels to sustainable sources (“There is a tendency towards sustainability, the balance will shift in that direction. There will be more green energy. People are willing to use renewable energy.”). There was no clear consent amongst the interviewees concerning the kind of sources that would provide sustainability. This was rather divided, ranging from atomic fusion to wind energy, from solar energy to wood stoves and electric cars. People often mentioned expecting a combination of several sustainable sources to be more plausible. (“I truly belief that we will become less dependent on fossil fuels because we will use new astonishing, easy ways to gain energy. I’m really talking about using different elements of nature”).

3.2 Hydrogen

First associations

In general, people’s first association of hydrogen was with chemistry and more specifically with the experience they had in high school. It was also often associated with water, which is not surprising given that the Dutch word for hydrogen is “waterstof”, which could be translated literally as “water matter”. The associations mentioned seem to cluster around two themes, with one group of interviewees only remembering hydrogen from their high school period, and the second group being aware of the developments of hydrogen and its use as a fuel over the last five to ten years. The first group often mentioned that they could vaguely remember the properties of hydrogen (“Hydrogen, I automatically think of water. No, I cannot remember the first time I heard it. I do have the feeling that it has been a long time ago”). Hydrogen was often confused with hydrogen peroxide and the chemical formula of water was often mentioned. Most people did think that the H in H_2O was the chemical element, although some confused the H with O from Oxygen. The second group was able to come up with at least some of the developments of the hydrogen over the past decade. Though this group was smaller, there were some interesting outcomes. People did make the connection between hydrogen and the use in transportation, especially cars and buses. People gave the example of buses based on the test buses riding in Amsterdam (“Yes, I remember that I heard about hydrogen about five years ago. Around that time buses started to drive on

hydrogen. And I also heard that there was a possibility to fuel a car with it. As an alternative for the present fuel options”). A few times hydrogen as a fuel came up. The hydrogen bomb was mentioned once, but hydrogen zeppelins were not mentioned at all.

Features of hydrogen

After the first spontaneous associations, people were asked to tell in what kind of shape or form they pictured hydrogen, if they had not mentioned this spontaneously. The interviewees mostly associated hydrogen with water, often in different states, imagining it being liquid or gaseous, mentioning steam, drops, fog and clouds. One person mentioned that the element hydrogen does not exist on this planet on its own. When talking about their encounters with hydrogen, people often mentioned experiences from their close surroundings, like the hydrogen buses in Amsterdam. Furthermore, the following misconceptions of hydrogen were mentioned: “it’s a kind of ‘carbon oxide’”, “it’s nitrogen” and “it’s in my hairspray”.

3.3 Hydrogen storage

Before interviewees were asked about hydrogen storage, a small explanation was given about hydrogen itself. This proved to be necessary to elicit any beliefs on hydrogen storage, as most interviewees just had too little knowledge on hydrogen to be able to associate hydrogen storage with anything, possibly leading to a very uncomfortable situation for the interviewee. This explanation was given by the interviewer and made sure that interviewees at least understood that hydrogen or H_2 is a gas that can be used as fuel. It was furthermore explained that hydrogen occurs naturally in very small amounts, and that more can be made but that this requires energy.

Awareness of hydrogen storage

None of the interviewed ever heard of hydrogen storage and very few gave spontaneous first associations (“When I think of hydrogen storage as a fuel for buses, I see some kind of gas station. With a container, maybe it is stored like some kind of gas”). Hydrogen storage proved to be a difficult subject for all interviewees. Since they never heard of it, they had difficulties forming an image. Most showed a surprised and curious reaction (“No, I don’t think I ever heard about hydrogen storage. I find it interesting and I would like to hear more about it”). Many started asking questions to the interviewer. There was no explanation given at first in order to be able to elicit associations and beliefs without influencing the interviewees. At a

later stage in the interview an explanation was given, this is described in a later section of this report.

Associations with hydrogen storage

The majority of interviewees mentioned a storage tank as their first association with hydrogen storage. Oil tanks, containers and silos were all mentioned. Many respondents saw storage of hydrogen under pressure as the solution. One respondent suggested that filling the empty natural gas fields with hydrogen could be the solution. Several more interviewees mentioned the possibility of hydrogen being stored underground but were less specific how exactly. Flammability and explosion was the main reason for the concern of safety (“If it’s a gas, I think you should be careful with it. Put it somewhere distant. The gasses which I am familiar with have the risk of combustion and explosion”). More interviewees stated an unsafe feeling regarding hydrogen storage as a concern. Very few interviewees saw a connection between hydrogen storage and using hydrogen as a fuel. Several imagined hydrogen storage as a contribution to the use of clean energy, although a few did not recognize it as a renewable application.

Asked about the use of hydrogen storage, a lot of interviewees gave the use of hydrogen as a fuel for vehicles as a first association of the use. Other frequently mentioned applications were using it as fuel to generate ‘some form of energy’ and the conversion of hydrogen to electricity. Some interviewees mentioned associated applications like household appliances and general use in the household. Interviewees had difficulties answering this question. They hesitated and more than once the interviewer had to rephrase the question several times before people came up with an answer.

Imagining specific aspects and consequences

People were asked to imagine hydrogen storage being implemented. What would change or what would they notice? Most interviewees thought they would not notice anything from energy delivery, comparing it to the present energy supply. Some thought that there would be different gas pumps at the gas stations, since cars would drive on hydrogen. Others predicted that the prices of fuel would change because of hydrogen being available at the gas stations.

The interviewees were rather divided about their ideal location to store hydrogen. Some proposed an industrial area, where others proposed little tanks in households. Business areas were mentioned a few times, as was storage at gas stations. A few interviewees came up with underground storage (“I think it will be stored under pressure, in underground tanks, as a fluid. I do believe that there will be strict requirements, because of safety reasons”). In general, interviewees stated that the storage should be very reliable. Several interviewees did not want the storage of hydrogen next to their home.

Most interviewees saw the present natural gas transportation system in the Netherlands as an example for hydrogen. A few of them proposed to use the exact same pipelines as a transportation meant for hydrogen. On the other hand, some claimed that storage should not be necessary; the place of production should be where it is used. The main reasons for this statement seemed to be the energy reduction and the safety (“I think it will be produced where it will be stored. I do not like transport. I can see the production and the storage next to the factory”).

Understanding

Several answers and associations of the interviewees showed the lack of understanding on the possible use of hydrogen storage as energy storage. Several questions were asked, designed to elicit interviewees’ ideas about this, but interviewees could rarely answer these questions, or came up with associations that are quite far from what is envisaged by experts. For instance when asked for what period of time they expected the hydrogen to stay at the location of storage, probing for their ideas on why the hydrogen is stored, most of the interviewees thought that hydrogen did not have an expiration date. Some did believe that it should be used within a certain amount of time. The reasons for this varied from the decline of ‘energy power’ to the waste of energy due to having to keep heating the water to produce hydrogen. This was related to the way some interviewees thought hydrogen would be produced. Many imagined hydrogen to be produced out of water, but several mentioned having no idea how to do that (“First you have to separate it from water. I have no idea how to do that.”). The most frequently mentioned was some sort of chemical process. One interviewee mentioned electrolysis. A few imagined taking the hydrogen from the steam of boiling water. One interviewee saw a cycle in the production: “You can make hydrogen with fire. After this you can use hydrogen as a fuel to produce hydrogen again”. None of the participants were really sure about their answers. Very few understood that you have to put in energy to take the hydrogen out of water or that energy is released when hydrogen burns

and becomes water again. It seemed that the majority did not understand the principle of energy being released when fuel is burned, or that burning means the binding with oxygen.

The lack of understanding of the use of hydrogen storage as envisaged by experts is also shown in the advantages and disadvantages interviewees mentioned of hydrogen storage. None of the interviewees came up with the use of hydrogen storage for renewable energy storage as an advantage. Interviewees indicated the sustainability (of hydrogen as a fuel) and the replacement of fossil fuels as biggest advantages of hydrogen storage. Some interviewees stated they did not see any advantages for the storage of hydrogen, but only for its’ use. Other advantages mentioned were “water is all around us”, “with hydrogen storage we will become independent from oil countries” and “ we can fill the holes, which emerge in the ground from taking the natural gas out, with hydrogen”. The disadvantages associated with hydrogen storage were danger of an explosion and the storage space it would occupy. A few interviewees were concerned about the amount of water needed to produce hydrogen, hydrogen being a danger to the environment or that hydrogen storage would not be needed yet. The amount of advantages and disadvantages mentioned did not differ much.

Most interviewees responded positively when they were asked about their interest in hydrogen storage. The reasons varied from “ Yes, but only when I would use it” to “Yes, I am interested in all the new energy sources”, or just a simple confirmation. Most had some conditions before expressing their interest. Some said that they were not interested at all. In general, people who stated that they were interested, showed this interest out of environmental consideration. Some were rather positive, thinking that it would be a smart new solution to energy issues, although few were able to explain why this could be the case. It seems several interviewees were vaguely aware of ECN’s mission and extrapolated that if we were asking about this technology, it would probably be sustainable.

Questions

The interviewees were asked what kind of questions remained after the explanation of hydrogen and after thinking about hydrogen storage. Most questions were aimed at safety (“How safe is the storage? I find this interesting. Suppose it is not safe, I guess the reaction of the environment and surrounding companies would be rather different”). These concerns about safety were linked with to comparison between hydrogen and natural gas. Interviewees often stated that because hydrogen is a gas, it would probably be highly

explosive. For example: “Hydrogen storage could cause a major explosion. I also do not want anything to happen with the present natural gas storage. It could be the same problem with hydrogen storage”. Many interviewees wondered whether hydrogen storage would be more sustainable than the energy sources they already knew. Most interviewees were interested in general issues like “How does the storage work?”, “Where will the hydrogen be stored?”, “How can we use hydrogen?”, or “How can we produce hydrogen?”. Others had more specific questions, like “Can you produce hydrogen out of salt and freshwater?” or “Does hydrogen storage have any implications for the building of new houses?”. More than once people asked these questions during earlier stages of the interview and repeated them when they had the change.

3.4 Reaction to information on hydrogen storage

After discussing hydrogen storage with interviewees without giving them any information, interviewees were given a text to read with information on hydrogen storage. The text is stated in the methodology section, but in short explained global warming due to use of fossil fuels and how underground hydrogen storage can support the use of renewables by functioning as energy storage to store surplus electricity coming from wind or solar energy. In general, reactions were very positive to this information. Almost all interviewees thought the information was clear and many interviewees were relieved to understand what hydrogen storage was about. The interviewees that had estimated underground storage were pleased they had estimated this correctly. Several interviews mentioned thinking storing the surplus energy of renewables is a very smart idea. (“The way I read it here, how it can be used, I think that’s good. It is a shame for this electricity to leak away. It is better to transform it into something durable. That we will do something useful with this energy in any case, is a top-notch idea in my book.”) A few mention an ’aha erlebnis’, finding the solution of hydrogen storage to deal with surplus energy from renewables quite logical.

3.5 Evaluation of hydrogen storage

People were divided in their opinions about hydrogen storage. This proved to be a difficult question because a lot of respondents felt that they did not have enough information to evaluate hydrogen storage (“It could be amazing and I believe it could work. But I only have a part of the information. If I would look into it, there might be a snag in it”). A lot of participants were interested, assuming more research would be done . The most positive association people had with hydrogen storage, was the underground storage. The

renewability of hydrogen storage and the use for implementation of more solar and wind energy, was mentioned by several interviewees as a positive thing. One person stated that the safety issue should be made clear, before hydrogen storage could be implemented.

The majority of the interviewees thought it would be necessary to implement hydrogen storage in the present energy mix. Most people thought of the combination of solar energy, wind energy and hydrogen storage as a foundation for a stable sustainable energy supply. This should be nuanced by the finding that most interviewees were not able to state many other energy options, so they might have been more happy with the only option given by the interviewer than had they been given a range of options. Another reason for the necessity of implementation that was mentioned was the importance of general development. A few respondents said that it would be a good alternative given the short term depletion of fossil fuels. Others stated cleaner air to be a good reason for using hydrogen storage. One person believed that it would be useful, but only when a small part of the energy mix would be reserved for hydrogen storage. A small amount of interviewees did not see hydrogen storage as an option for the present energy supply. A few stated that renewable sources should not be developed until all fossil fuel sources have been depleted. One individual did not want to respond to this question due to a lack of information to base evaluation on. In general, it seemed like people were mostly positive about hydrogen storage.

Leftover questions

At the end of the evaluation people were asked whether they had any questions left about hydrogen storage. These question were not answered by the interviewer, but they are an indication of the issues people still had with hydrogen storage after the free association, the small explanation about hydrogen and the text about hydrogen storage. The most asked question was how hydrogen storage would work. Furthermore people were interested whether hydrogen storage was already in use. There were still some participants concerned about (their) safety. Some considered the emission of hydrogen storage to be important. People also asked questions about the use and the production of hydrogen, such as “is hydrogen cheaper” and “how much energy does it take to produce it”. Besides this, many separate question were asked. Most of them addressed technical aspects of hydrogen storage or use. Compared to the questions the respondents asked in the middle of the interview, interviewees seemed slightly less concerned with hydrogen storage being safe or renewable.

3.6 Related associations

Almost all respondents could name at least one example of storage, next to storing hydrogen. Most frequently stated was storing oil in tanks. Many respondents mentioned storing nuclear energy[2] as an example, and several thought solar panels store energy as well. It was clear from the answers that many ways of producing electricity were seen as energy storage, a lot of interviewees seemed to have the idea of power plants or solar cells as batteries being charged in different ways. This was after the text explaining the need for surplus energy from wind turbines or solar panels to be stored with the help of some form of energy storage, for instance hydrogen storage. Some interviewees came up with the example of the battery. The possibility to store energy in biomass was only mentioned once. Storage reservoirs and underground storage of energy were stated a couple of times. A few people had an association with natural gas storage. None however mentioned either CO_2 storage or the storage of nuclear waste. One interviewee did mention hearing about the controversy surrounding the plans for storage of a gas in a village. Given recent controversies surrounding storing gas in the Netherlands, this could either be natural gas or CO_2.

When interviewees mentioned other energy options during the interview, they were asked further about their perception of these options. A few interviewees mentioned the long period of existence, the low price and the distribution network as benefits of storing oil in tanks (“Oil is present at any time you want, you can process, transport, and use it relatively easy”). Many respondents saw disadvantages to the storage of oil: mentioning it being unsafe , taking up a lot space, some tanks being empty and the storage costing energy. As for nuclear energy, a few interviewees thought that this would be inexhaustible, and that it would be a clean and cheap form of storage. Others qualified it as dangerous and one respondent thought it was bad for the environment. For batteries people mentioned advantages such as existing techniques, easy to get, well protected, always at hand and compact. In general respondents did not see batteries as sustainable examples of storing energy. Mostly heard disadvantages: the length of charging, the weight, the space it takes up, capacity loss after an amount of time (a problem with electric cars), and aging. The only benefit of renewable sources was their perceived cleanliness. Solar energy was said to be cheaper and the advantage was stated by some that the owner would be independent of the energy

[2] Specifically nuclear energy was mentioned, not waste. People thought nuclear energy was storable, but weren’t clear on how or in what.

companies. According to a few interviewees, renewable energy sources like wind and solar energy were not stable enough. Solar energy was said to be unsafe because the panels could catch fire. A few respondents stated that biomass takes up too much space and is unsafe. Many stated that storage underground does not take up any space above ground, which is important in a crowded country such as the Netherlands (“Underground storage, this can become more important in the future. A pro is that it does not matter for the view and it does not take up a lot of space. This is a big advantage”). A general comment placed by a respondent was that storage costs a lot of energy. Storage reservoirs were said to have a time and attention consuming infrastructure.

In general, the discussions on the range of energy options and specifically energy storage seemed to cause many interviewees some anxiety. Several mentioned not knowing enough about this and being anxious about the possible consequences of all these options, specifically about safety.

Associations with climate change

All interviewees believed that human beings had some kind of influence on climate change. Some thought that living more economically would give them a certain amount of control, for instance by cycling instead of driving, by dividing garbage or by buying biological products would give them a certain amount of control. A few others had a broader perspective and saw renewable sources or less pollution as the solution. However, when asked later about possible action to avoid further climate change, none of the interviewees mentioned renewables. Many interviewees did mention saving energy within the household and a few mentioned isolating the house. Some interviewees did not believe that the measures taken in the Netherlands against climate change, would have any effect.

4 Discussion and Conclusions

Recently, the European Commission has set the 20-20-20 target (20% GHG emission reduction versus 2005, 20% renewable energy share, 20% energy efficiency increase). Because of this, a more strongly fluctuating energy supply will be very likely, causing the need for energy storage. This will confront society with emerging technologies that are unknown to most lay people (1). One of the possibilities for energy storage is hydrogen storage, studied in the HyUnder project, of which this study is a small part. How the public will view hydrogen storage could be of crucial influence on its’ implementation. Previous research and experience have shown that the public can have very different views and concerns about these issues than experts, and a lack of attention to this has caused major problems in other energy projects (2,3). Currently, little to nothing is known regarding public perception of energy storage, specifically regarding hydrogen storage. The current study therefore explored lay people’s beliefs, ideas and evaluations of hydrogen storage and associated concepts.

As discussed in the introduction section of this report, there are some methodological challenges to studying public perception of something that is most likely unknown to most of the public. Earlier research shows that a significant part of respondents to surveys does not refrain from giving their opinion, but responds with “pseudo-opinions” or “non-attitudes” (5, 6). These sorts of “uninformed opinions” have been shown to be unstable and easily changed by contextual information, and can therefore not be seen as predictive of actual public opinion once the public is confronted with plans for actual projects (6, 7, 8, 9, 10). Furthermore, these sorts of opinions would not be a reliable basis to support communication efforts. One of the ways to tackle this issue is to give people information before asking for their opinion. However, earlier studies also show that even with very reliable, valid and understandable information from experts on energy options, people base only part of their opinion on this information from experts (9). Apparently, other beliefs play a significant role as well. Several studies indeed find that lay people can have ideas and beliefs about energy options which are generally not addressed by experts and which sometimes are factually inaccurate (11, 12, 13, 14). For a first study on public perception of hydrogen storage, a more elaborate exploration of lay people beliefs regarding this and associated topics with qualitative methods therefore seemed warranted. The current study used the mental model approach with in-depth interviews using a rather open interview protocol, eliciting public beliefs and perceptions by allowing interviewees to express their beliefs and perceptions of hydrogen storage and associated topics freely without being influenced.

Awareness issue

As expected, people were rather unaware of the option of hydrogen storage. In general, people were not familiar with energy sources and energy transition overall. There were many misconceptions regarding the amount of use of certain energy sources and technologies and about other possibilities. Although most people had heard of hydrogen and had some associations, not many were correct and few people fully understood the possibilities of hydrogen in regard to energy. None of the people had heard of hydrogen storage, or understood the necessity of energy storage to ensure reliability of energy supply when implementing a higher share of renewables in the energy mix.

Associations and understanding

Most interviewees associated hydrogen with water, which might be explained by the Dutch word for hydrogen, which is “waterstof”, or in English “water matter”. Many mention the association with chemistry in general, and several people knew that it can be used as fuel. Due to the association with water, many misconceptions came to light about the aspects of hydrogen. Therefore few people mentioned a risk of explosion, but also few people understood the possible use of hydrogen. People had a very hard time imagining why one would want to store hydrogen. Most mentioned was the association with gas stations, so the use of storage was to have it available for transport. Some people thought it could be stored to use as fuel for power stations, some thought it could be stored at home to use for electricity there. Few people thought it could be stored underground. There was a severe lack of understanding regarding the possibilities of hydrogen as energy storage option for surplus renewable energy. Practically everyone lacked the knowledge to understand the whole chain of reasoning; from the need to increase use of renewables, to the problem of intermittent energy supply by renewables, to the need to store energy, to hydrogen being a possibility for this, to how to produce hydrogen, etcetera. For instance, many people mentioned generating energy by heating water, seeing steam as hydrogen. Few understood that energy is needed to produce hydrogen, or understood the law of conservation of energy. None realized the problem with increased use of renewables for continuous energy supply, hence the need for energy storage. However, after people were given information on this reasoning, they were mostly quite enthusiastic. Several people found it a smart solution and see the combination of wind and solar energy with hydrogen storage as the best option for energy in the future. However, this conclusion should be nuanced by the fact that most interviewees had a hard time envisioning any other options for our future energy system, and might have jumped at the option that was readily available to them, i.e. the option given during the interview.

Some people did worry about the risks of hydrogen storage, but most saw that as easily solved by storing the hydrogen away from populated areas. The hydrogen being stored underground did not seem to be much of an issue. Many interviewees did state to feel uncomfortable coming up with opinions on something they had so little information about, and said they might change their opinion once they had more information, for instance about risks and costs. Several interviewees also stated the intention to look for hydrogen storage in Google as soon as the interview was done.

Implications

This study shows a major lack of knowledge with lay people about our current and future energy system, and specifically about the role hydrogen storage could fulfill. This finding is not very surprising, as several studies that investigated lay people’s knowledge of energy options and the energy system find a low level of awareness and knowledge on this topic in the general population, both in the Netherlands where this study was done (i.e.11, 15) as in all of Europe (16). So although one cannot draw any quantitative conclusions based on 16 interviews, studies investigating awareness and knowledge of other new energy technologies using representative samples do corroborate this finding of a general lack of awareness and knowledge regarding our current and future energy system. Specifically for hydrogen storage though, one should be careful not to interpret the results of this study as being representative. For one, because a sample of 16 always leaves a risk of not being representative. Half the interviewees having a certain association in this study might not translate to half the Dutch population for instance, for that a much larger sample is need to draw statistically sound conclusions about the prevalence of certain beliefs, associations, and evaluations. This studies only shows the sort of beliefs, associations and evaluations in the Dutch population, not the percentage of people having them. Secondly, because it is likely that the general population differs from a local population that is confronted with actual project plans. We will discuss these two groups separately, as very different psychological processes come into play in case of the latter group.

Considering the general population, the findings of the current study show a likeliness that people will not understand the benefits of storing hydrogen, but might associate it with perceived risks such as explosion. However, the results of this study do suggest that people might be quite positive about this option once they understand how storing hydrogen can be used as energy storage needed to support an increase in the use of renewables. Again, this conclusion should be drawn with caution, as this a qualitative study, and not representative

of a larger population. Moreover, the interviewees were Dutch and the range of beliefs and associations in other countries might be different. Also, giving information does not create acceptance or a positive opinion, as for instance Fisschoff shows in his review of twenty years of risk communication research (17). Often opinions become more polarized (18), in the sense that people that were somewhat neutral towards the topic before information become more negative or more positive after information. Mostly opinions become more stable after information, meaning informed opinions are more stable over time and are influenced less by new information (19).

The associations and beliefs found in this study can be helpful when developing communication efforts. When developing communication efforts, and specifically when it comes to information, it is crucial to match the information that is being developed to the actual information need of lay people. Mismatches in earlier cases sometimes have caused the opposite effect of what was aimed for, either because people felt belittled when the information was too simplified, or because it was misinterpreted when it was too difficult (4). Knowing the possible beliefs and associations, or even misconceptions, about a technology aids to avoid such mismatches. For this the current results are not sufficient. A quantitative follow up study using a sample that is representative of the population the communication is aimed at will be necessary for that. However, the chances of any communication campaign for the general population being effective for a topic that is so little top of mind and so little personal for people could be called slim; it seems unlikely that the communication effort that is needed for awareness in the whole population, comparable for instance to certain health campaigns, can be realized for a topic such as hydrogen storage.

Considering local populations in areas where hydrogen storage might be planned, many other factors come into play. Although this study does give an indication of possible associations and beliefs, locally these might be different. It is for instance likely that in places where hydrogen can be stored, other substances have been extracted, such as natural gas or salt. In this case, the industrial activity and the organizations involved are likely to be known already to local people and earlier experiences are likely to have an influence on the perception of further plans. Many factors are known to influence this, often interacting with each other, such as the local demographics, place attachment, earlier experienced risks, expected procedural justice, trust in the local, regional, and national government as well as trust in project developers, awareness, knowledge and perceptions of energy options and the energy system in general, and many others (20). In general, opposition to projects often does not come from opposition to the technology, but is rooted in the project approach itself.

Traditionally, this approach is strongly project-oriented, focusing on ‘hard’ (technical, economic) project criteria, when what is really needed is procedural justice, having a voice in the detailing of the project. Many times there is the perception of limited opportunity to examine the procedure, none or little room to exert influence and not enough time and information to develop a well-informed opinion. This often leads to local people feeling that the deal is done before they are involved and therefore possibly leads to people going through great lengths to frustrate and delay the process (2,3). In specific hydrogen storage projects the authors’ advice would be to apply social site characterization or a similar process of attaining good knowledge of a project environment at the start of the planning process. Each project and its’ environment is unique, and therefore management of public participation and communication processes will only be effective if it is tailored to the situation.

4.1 Conclusions

This study is to our knowledge the first investigation of lay people’s beliefs of and associations with hydrogen storage. Through 16 in-depth interviews following the mental models approach lay people’s concepts of this issue were explored. Analysis shows that the interviewees were hardly aware of hydrogen or its’ possible use, and none had heard of hydrogen storage or came close to guessing its’ possible use as energy storage for renewables. The first associations were of chemistry and water in gaseous form and of fuel. Other common associations were risk of explosion, fuel storage and tanks. After some information explaining the use of underground hydrogen storage as energy storage to mitigate intermittent supply of energy with wind turbines and PV, most people were enthusiastic, but also mentioned having little information and possibly changing their opinion if they learned of consequences they had not considered. This investigation of the range of possible beliefs and associations required a qualitative design, therefore the sample was too small to draw conclusions about the prevalence of said beliefs and associations in the population.

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