Social impact of the underground H2 storage

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Revision History

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List of Acronyms

CO_2	Carbon dioxide
E-LCA	Environmental Life Cycle Assessment
EN	European Normative
ES	Spain
FR	France
FU	Functional Unit
H_2	Hydrogen
moh	Medium opportunity hours
mrh	Medium risk hour
NGO	Non-Governmental Organization
S-LCA	Social Life Cycle Assessment
SMR	Steam Methane Reforming
UHS	Underground Hydrogen Storage
WP	Work Package

1. Executive summary

The study developed under the Hystories project focuses on the assessment of viability of the large-scale underground storage of pure hydrogen in aquifers and depleted fields, including main feasibility issues, providing market and impact studies including the economical, environmental and socioeconomic aspects of the deployment and exploitation of underground hydrogen storage in Europe.

In the frame of Work Package 6 (WP6) the Environmental and Societal impact studies have been carried out with aim to assess the economic feasibility, environmental and social performance of selected sites for pure hydrogen storage, including aquifers and depleted field sites. The results of these studies will serve as a key input for defining the implementation plan for underground renewable hydrogen storage in the EU by 2050 (WP9).

The task 6.3 is dedicated to Social Impact study conducted with the use of elements of the Social Life Cycle Assessment (S-LCA) methodology, tailored and combined with the social perception study in order to present beliefs and public opinion and potential social impacts related with the deployment of underground large-scale hydrogen storage and its impact on different types of stakeholders including workers, society and local community actors.

The aim of this report is to present the results of the social impact study based on the analysis and methodology tailored to encompass the characteristics of the project and split into two parts, where the first part was based on the generic data provided by the PSILCA, being a dedicates social impact database, in order to assess the potential impact of the large-scale underground project and the second part based on the primary data collected with the use of dedicated questionnaires developed for two main groups with different level of knowledge related to hydrogen and to underground hydrogen storage. These two groups are the general public and, on the other hand, experts previously involved and familiar with projects of similar character related with underground hydrogen or natural gas storage.

One of the objectives of the Hystories Project was to develop a social impact study for large scale underground H2 storage, considering the importance of local communities near an underground H2 storage facility being comfortable with this new technology being deployed in the region of the local community. Therefore, the aim of the social perception study is to support the development of S-LCA evaluation of underground hydrogen storage providing such information as the degree of technology acceptance and factors deciding on technology acceptance and its impact on society.

This report consists of 7 sections including executive summary, introduction and methodology presenting the approach implemented for both parts of the study. The 4th and 5th sections are dedicated to the development of both parts of the study where, on one hand, Part I comprises the hotspot analysis, including the definition of goal and scope, functional unit, social impact categories, assessment and the results, while on the other hand the Part II of the study presents the study conducted on both stakeholder groups (experts and general public) together with the result presentation and analysis. The 6th section presents the summary and conclusions drawn based on the results obtained from Part I and Part II. The last chapter includes the references and bibliography used in this study.

2. Introduction

Renewable energy sources such as solar and wind are becoming increasingly popular around the world as countries seek to reduce their dependence to fossil fuels and mitigate the effects of climate change. However, one of the main challenges with these energy sources is their intermittent character, meaning they do not provide a steady supply of energy at all times. This intermittency can be addressed among others by energy storage systems that can store excess energy when it is generated and release it when it is needed.

There are many different types of energy storage systems, including batteries, pumped hydro, and thermal storage. However, one promising option that is gaining traction is underground hydrogen storage. Hydrogen has the potential to be an excellent energy storage medium as it can be produced from renewable energy sources and water, and can be stored for long periods of time without major losses in terms of its energy content.

Underground hydrogen storage involves storing hydrogen gas in natural underground formations such as salt caverns or depleted oil and gas reservoirs. When the stored hydrogen is needed, it can be retrieved and used to generate electricity through fuel cells or direct combustion. This process can be used to balance the fluctuations in renewable energy generation and provide a reliable source of energy for consumers.

Despite UHS (Underground Hydrogen Storage) being promising rising technology, one of the issues that might have a crucial influence on this technology´s implementation is the social acceptance and the possible social impact this developing technology might exert on various groups of stakeholders such as workers, society or local community.

Previous studies proved that the public opinion and acceptance is strongly dependent on many factors leading to different public beliefs and views on the technology, whereas the concerns are mostly driven by the level of knowledge related with the technology under investigation, the possible risks associated with the technology and the general publics´ awareness about the technology leading to a certain extent of opposition from local communities [1]. Overall, successful implementation of underground hydrogen storage will require effective communication, community engagement, and a comprehensive approach to addressing potential risks and concerns.

Regarding the Social Life Cycle Assessment (S-LCA) of underground hydrogen storage technologies and hydrogen technologies in general, previous research showed that there is a scarcity of studies where this methodology has been applied given the S-LCA to be a relatively novel area and not yet as well developed as Environmental LCA methodology, which has been a base for the creation of the social aspect for Life Cycle Assessment (LCA) studies [2]. LCA is a methodology used to evaluate the environmental impact of a product or system throughout its entire life cycle, from the extraction of raw materials to the disposal of the final product. While the goal of LCA is to identify and quantify the environmental impacts associated with each stage of the life cycle, including the production, use, and disposal of the product, the aim of S-LCA is to investigate the social impact of those stages on various groups of stakeholders. However, both methodologies are used to evaluate the impacts of a system or product, there are some key differences to be addressed. While the primary focus of LCA is to evaluate the environmental impacts of a product or system, the S-LCA primarily focuses on the social impacts, including social equity, human rights, and community well-being and other social themes such as those previously addressed in Hystories report *D6.2-1-Final definition of impact categories and indicators for E-LCA and S-LCA*.

According to 2009 UNEP/SETAC Life Cycle Initiative, Social Life Cycle Assessment is a technique to evaluate both positive and negative social impacts of a product along its life cycle. It should be highlighted that the main feature of S-LCA methodology is that the data used for this kind of study is subjective and the stakeholder's perspective plays a significant role. Moreover, the S-LCA is strongly dependent and associated with the location, as different levels of selected negative or positive social impacts might occur in different countries and for different sectors [3].

In order to address the possible social issues and include a stakeholder´s perspective, a tailored study involving both S-LCA and public perception study has been conducted. The study has been realized by dividing the social impact study into two main parts. The first part has been using secondary data using openLCA software for the development of product life cycle analysis and social data contained within dedicated PSILCA database. The second part of the study has been based on primary data and involved the creation of two types of questionnaires dedicated to two groups of stakeholders with different experience in hydrogen field and underground storage of hydrogen and/or natural gas. The first group concerned the project stakeholders, and thus experts with previous experience in similar projects. The second type of questionnaire has been created in order to investigate the beliefs, level of knowledge and general acceptance of technology among lay people. More detailed description of the social impact study methodology concerning Part 1 and Part 2 of the study has been presented in the Section 3.

3. Methodology

The methodology used for the social impact studies has been tailored in order to obtain reliable results addressing both the S-LCA of underground hydrogen system, the public perception and acceptance of this technology. The social impact study has been divided in two main parts: Part I – based on the secondary data and Part II – developed with the use of primary data as presented in Figure 1. Part I, based on secondary data has been conducted based on the S-LCA methodology with the use of software and dedicated social impact database aiming to detect the sectors with highest contribution to the previously selected social themes and addressing various stakeholders. This study allowed to conduct the hotspot analysis for selected social impact categories and stakeholders indicated in the Hystories Deliverable 6.2. Part II of the study has been conducted based on the collection of primary data and it involved various questionnaires distributed among selected respondents focusing on one hand, the general public and, on the other hand, the project stakeholders familiar with hydrogen and underground gas storage technology.

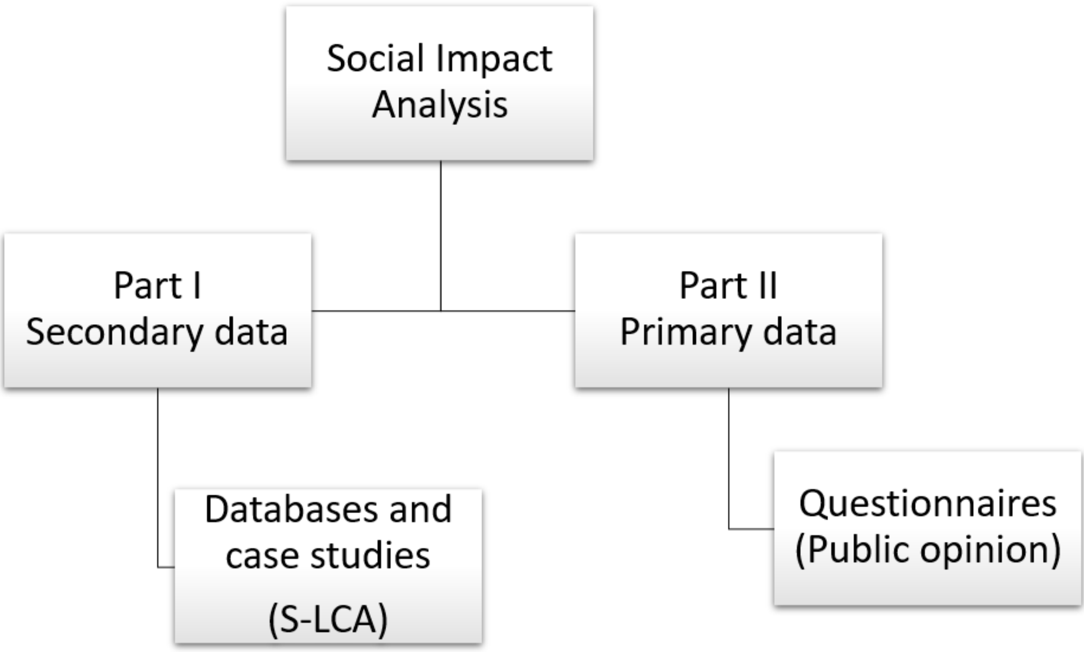

Figure 1 Division of the Social impact study conducted under the Hystories project.

3.1.Part I - S-LCA hotspot analysis (secondary data)

The S-LCA methodology has been based on the LCA methodology and thus follows the standards ISO14040 and ISO14044. The UNEP/SETAC Guidelines for Social Life Cycle Assessment have been defined gathering the instructions and tools for the assessment of social performance of businesses, products and organizations, following the international standards on social responsibility, human rights and Sustainable Development Goals (SDG).

The definition of the goal and scope of the study is therefore the first step of the standardized LCA framework. At this stage is also important to recognize the importance of the location of the system under investigation given the significant influence of geopolitical and economic profile of the countries on the quantification of the social impact categories considered for each product system.

The second step is the collection of data necessary to perform the S-LCA analysis. According to UNEP Guidelines for Social Life Cycle Assessment of Products and Organizations 2020, the secondary data are those which can be collected via literature or web research [2]. Additionally, these data can be collected using existing databases. For this purpose, PSILCA database together with openLCA software for LCA study have been selected to perform this part of the study, which allowed to directly conduct hotspot assessment of underground hydrogen storage for both technologies under investigation, being the underground hydrogen storage in porous media and salt caverns [4].

The third step, being the impact assessment, has been performed for this study by grouping the specific stages and its respective elements into sectors readily available in the PSILCA database. In the S-LCA methodology the quantification of the impact assessment for each selected impact category is associated with the unit of *medium risk hour* (mrh) or, in case of positive social impact, the term of *medium opportunity hour* (moh) per FU is used. The quantification of the social impact and selected social indicators for the hotspot analysis has been based on the information contained directly in the PSILCA database.

In order to perform complete S-LCA analysis, implementation of an activity variable is required, where, according to Benoît et al. 2009, activity variable is a measure of a process activity or scale which can be related to process output and which reflects the share a given activity associates with each unit process [5]. Activity variable can be expressed in two ways: either by calculating the working hours per FU or indicating the value added for FU. Further, the social impacts are being calculated as a product of the activity variable and the level of risk (intensity variable) associated with the selected social themes in terms of mhr or mro for the country-specific sectors included in the supply chain of the product system.

Additionally, in order to build the life cycle product system and calculate the activity variable per 1 USD output from each sector, such values as labour cost, mean hourly labour cost and a product´s market price are required to create the connection between the processes. This need results from the fact that PSILCA database on Eora database as a backbone, which utilizes monetary process connections.

Therefore, given the complexity of the project system, early stage of technology readiness level and scarcity of reliable data, including necessary sector and product related economic data, a social hotspot screening has been conducted in order to highlight the sectors with highest social impact, considered under Hystories project [6].

Figure 2 shows the division of the processes included in the life cycle of the underground hydrogen storage considered within Hystories project based on the data included in the Deliverable 6.3 and their aggregation into sectors available in PSILCA. The stages presented in the Figure 2 include the most important foreground processes for which Spain has been selected as a country of reference. The remaining background processes have been included as default processes linked with the selected processes of the sectors included in the underground hydrogen storage technology. The interpretation of the social hotspot analysis has been performed and presented in the section 4.7.

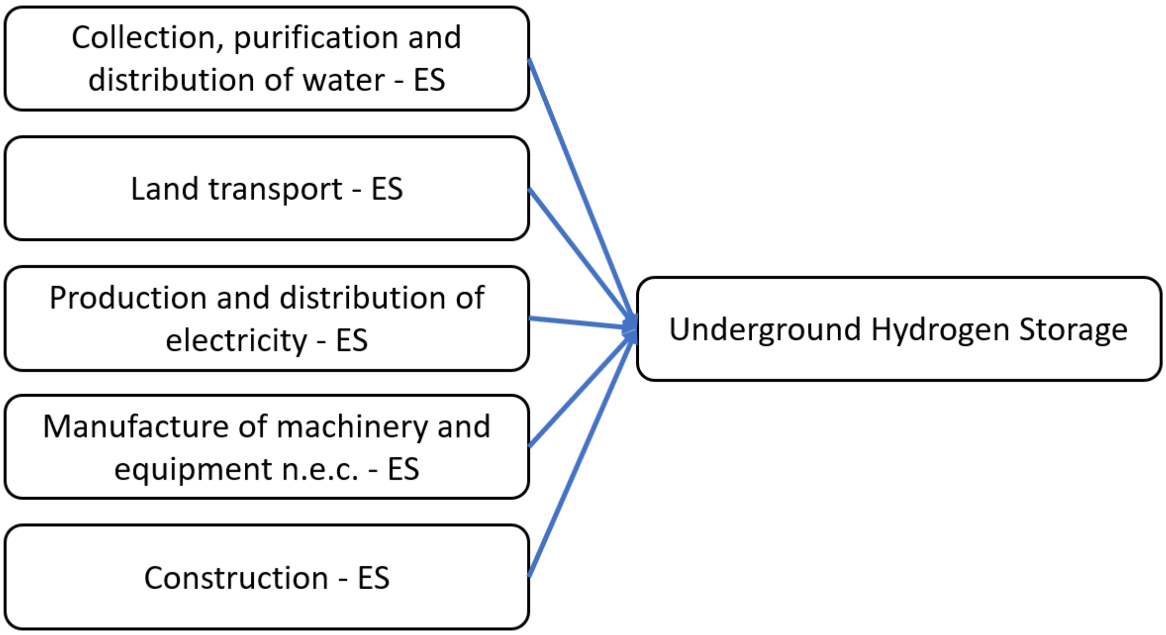

Figure 2 Division of the underground hydrogen storage product system into sectors

3.2.Part II - Public perception study (primary data)

The Part II of the Social impact study, involved primary data, meaning data which collection is usually carried out by visiting specific production sites or by working together with organizations and companies, through NGOs, via auditing process, observations of business/production or through interviews or surveys with stakeholders, such as workers or local community, that might be affected by the project[7]. In order to provide analysis of the public perception on the underground hydrogen storage, two groups of stakeholders have been selected being, on one hand, the project stakeholders, having an expertise related with hydrogen technologies and, on the other hand, the representative of local communities of three countries being investigated under Hystories project: France, Spain and Germany having different level of knowledge related with hydrogen and underground storage technologies. The study has been conducted by spreading two types of questionnaires tailored to both of the selected groups of stakeholders. The first type of online questionnaire dedicated to project stakeholders has been launched via Microsoft Forms and distributed with the help of

Hystories Project Consortium. It contained a total of 8 questions related with previous experience with similar projects involving the underground gas storage, the possible challenges related with public acceptance of the technology and lessons learned. Questionnaire dedicated to project stakeholders has been distributed to Advisory Board members of Hystories project and the members of Task42 of the Hydrogen Implement Agreement managed by the International Energy Agency, dedicated to the study of UHS. A total of 13 answers has been collected.

The second group of stakeholders involved the representatives of various profiles and age groups from three EU countries being France, Spain and Germany. The study has been conducted via online questionnaires created by FHa and launched and distributed by Voxco company specialized in the internet panel surveys and gathering market data. The questionnaire has been composed of 3 main sections, being: 1) Baseline questions; 2) Measuring awareness; 3) Influencing factors.

Section 1) Baseline questions contained the standard questions in order to assess the respondents´ profile including their age, sex, level of education, profession and questions for initial evaluation of their interest in environmental issues, level of knowledge of renewable technologies, hydrogen, energy storage and level of familiarity with other renewable technologies available on the market. This section included mostly closed questions with provided 5-point scale and one open question. The section included in total 13 questions.

Section 2) Measuring awareness contained specific questions reflecting respondents' beliefs regarding both hydrogen in general and underground hydrogen storage technology. This section was composed of 10 questions in total, with 5 questions addressed to hydrogen in general and 5 questions dedicated to measure the awareness and assess the responders´ familiarity with underground hydrogen storage. Additionally, this section contained two short definition "Information about hydrogen" and "Information about hydrogen storage" in order to minimize bias and number of random answers.

Section 3) Influencing factors has been introduced in order to assess various factors that might be influencing respondents´ attitude towards underground hydrogen storage technology. Factors such as increased traffic during construction phase, general uncertainty, job creation, noise pollution and willingness of respondents to live in the vicinity of the underground hydrogen storage site has been assessed in these sections.

A total of 322 answers from all the targeted countries has been collected. It should be recognized that this study is one of the first of its kind performed at this scale, following the example of a study first introduced under the Hyunder project, being a pioneer investigation for the assessment of the public perception of underground storage caverns by conducting 16 in-person interviews [1].

4. Part I – S-LCA hotspot analysis

4.1. Goal

The main objective of the study is to evaluate the performance of two underground hydrogen storage systems in terms of social impact, for a better understanding and implementation of the impact associated with large-scale underground hydrogen storage.

The principal purpose is to assess the potential social impact and screening of the largest social impacts (hotspots) associated with the sectors involved in the underground hydrogen storage under investigation. This study is directed to the partners of the Hystories project and other parties interested in the topic being the intended audience.

4.2. Functional unit

The functional unit (FU) selected for the system under consideration has been based on the assumptions presented in the D6.3 *Report on the environmental impact of the underground H2 storage*.

It should be noted, as defining the FU is important for determining the reference flow, it usually serves to use a S-LCA database in case of performing complete S-LCA study expressed in monetary units due to the use of trade models. In some cases, and for social impact that do not necessarily depend on the physical flow and the nature of unit processes, but rather on the behaviour of the companies and stakeholders involved in the life cycle, the common practice might be to provide results that are not scaled to the functional unit. The absence of this scaling factor can be performed due to practical reasons, such as data shortage or conceptual reasons when the social impacts are not scaled linearly [2].

The FU is the underground storage of 1 kg of H_2 produced through an electrolyser, stored for an annual cycle for both storage sites with a quality of 99.93%, a pressure of 55-180 bar for salt cavern or 55-130 bar for porous media and a temperature of 40-60 °C. The lifetime of both theoretical underground H_2 storages considered (salt cavern and porous media) is estimated to be 50 years.

The social hotspot analysis has been performed for the underground storage of 1kg of hydrogen.

4.3. Software tool and data sources

S-LCA hotspot analysis has been performed with openLCA software. Inventory data were based on secondary data retrieved from dedicated social impact database PSILCA [4]. Additionally, primary data provided by Geostock served for defining the division of system and aggregation of the inputs and outputs into sectors readily available in PSILCA database.

4.4. Impact assessment categories

The social impact assessment categories for the socioeconomic assessment of underground H_2 storage have been selected based on the recommended social topics presented in the UNEP/SETAC Guidelines [2]. Five social impact indicators have been selected in order to characterise the social performance of the system. The indicators have been previously presented in the D6.2 *"Final definition of the impact categories and indicator for the E-LCA and S-LCA"* and are relevant for the countries and sectors involved in the scope of the study.

Table 1 Selected social impact subcategories related to different stakeholder groups.

Stakeholder category	Subcategory
Worker	Fair salary
	Working hours
	Health and safety
	Equal opportunities/discrimination
Society	Contribution to economic development

Those impact categories translate to the options available within PSILCA database as fair salary (FS), weekly hours of work per employee (WH), fatal accidents (FA), gender wage gap (GW), contribution of the sector to the economic development (CE).

4.5. System boundaries

The boundaries of the system for which the hotspot analysis has been performed consider the most important foreground processes for the selected sectors, excluding such background processes as material extraction and manufacturing of basic materials (except the manufacturing of the machinery and equipment necessary for the construction phase). The social hotspot analysis therefore considers the cradle/gate-to-gate boundaries as the use and abandon phase are not being included in the scope.

4.6. Impact Assessment

The social hotspot screening has been performed for the sectors within Spain (ES) for the identification of social risks, hotspots and opportunities for and the most contributing processes within the system under investigation. The impact assessment has been performed using the ’openLCA software and the results are based on the information contained within PSILCA database expressed in mrh and moh.

4.7. Results

The results of the social impact analysis present the highest five contributions from the sectors under consideration to the selected impact category. The results are expressed in mrh (or moh, given the risk can be positive) and are expressed per FU, being 1kg of hydrogen stored. Additionally, it should be recalled that in PSILCA the worker hour activity variable is expressed per 1USD of process output. Additionally, social risk is measured in medium risk hours, which reflects the number of worker hours along the supply chain that are characterized by a certain social risk. Therefore, higher values correspond to higher risks (i.e. more negative performance) or higher opportunity in case positive risk is considered [8]. The performance has been measured for the sectors located in Spain. It should be noted that the contributions coming from category ´Other´ also include background processes linked with different countries of origin and thus having a higher impact. As only foreground processes and their related sectors have been considered for the hotspot screening, this category will not be analysed in detail and thus will not be taken into account.

The first results present the sectors´ contribution and its social performance within the ´Fair Salary (FS)´ impact category as reflected in Figure 3. The highest contribution in this category comes from the Construction - ES sector resulting in almost 1.5 mrh followed by 1.1 mrh related with the Manufacture of machinery and equipment - ES. Considerable contribution as well comes from the Collection, purification and distribution of water – ES reflecting the value of 1 mrh. The remaining contributions comes from the other types of market land transport – ES and Other land transport; transport via pipelines – ES representing the values of 0.96 and 0.94 mhr respectively.

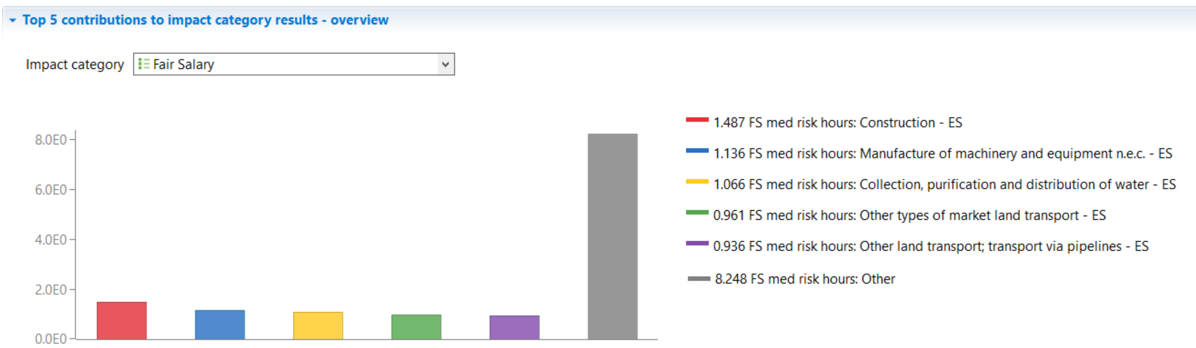

Figure 3 Results of the UHS sectors´ social performance in the Fair Salary (FS) impact category.

The second selected social impact category considers the Weekly hours of work per employee (WH). The highest contribution has been detected in the Mining and quarrying (energy) - RU sector, however given this process has been located in Russia, therefore does not lie within the scope of the study and will not be considered for this analysis. Similar situation can be seen in case of smallest contribution coming from Collection, purification and distribution of water – IR in Ireland which forms part of one of the background processes. The following contributions have been identified for such sectors as Public Administration – ES, Metal products – ES and Residential building construction – ES with reflecting almost negligible risk of the order of 2.2-3.2 thousandth mrh. The exact values have been demonstrated on the graph presented in the Figure 4.

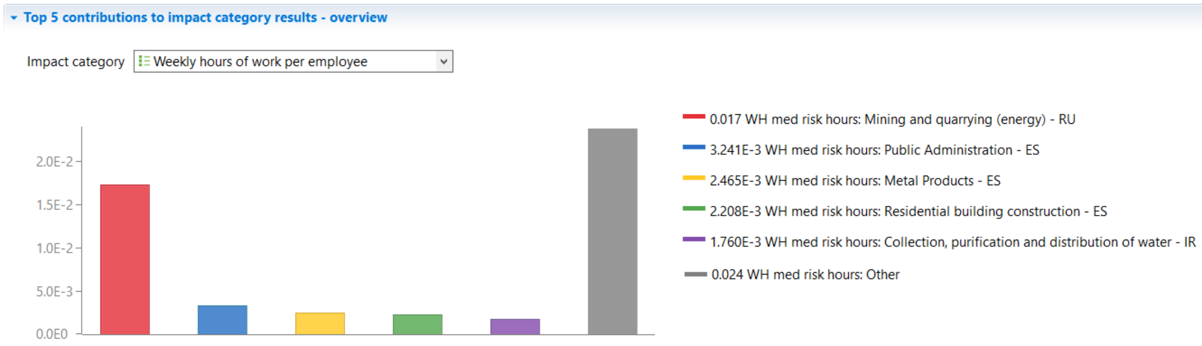

Figure 4 Results of the UHS sectors´ social performance in the Weekly hours of work per employee (WH) impact category.

Regarding Fatal accidents (FA), the highest contribution could be spotted in the Mining of coal and lignite; extraction of pean – ES, with the value of 1.4E-4, which corresponds not only to negligible contribution, but also it reflects the risk associated with one of the background processes´ components. The remaining contributions come from the Construction – ES, Manufacture of machinery and equipment – ES, Collection, purification and distribution of water – ES, however all of them present minor values of ten-thousandth.

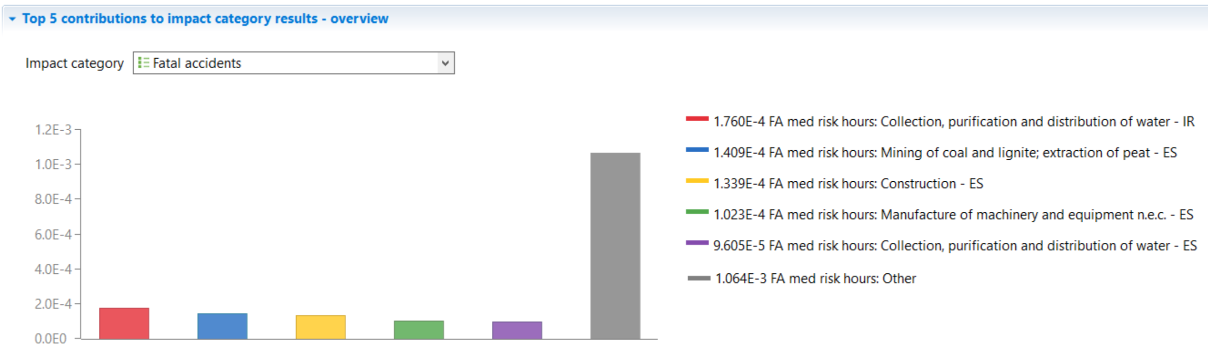

Figure 5 Results of the UHS sectors´ social performance in the Fatal accidents (FA) impact category.

The Gender wage gap (GW) impact category showed that the highest probability of this risk to occur with Spanish sector is related with the Manufacture of machinery and equipment – ES, reflecting the value of 0.1 mrh. Values around ten times lower can be observed in the remaining sectors contributing to this impact category being Collection, purification and distribution of water – ES, Other types of market transport – ES and Other land transport, via pipelines – ES.

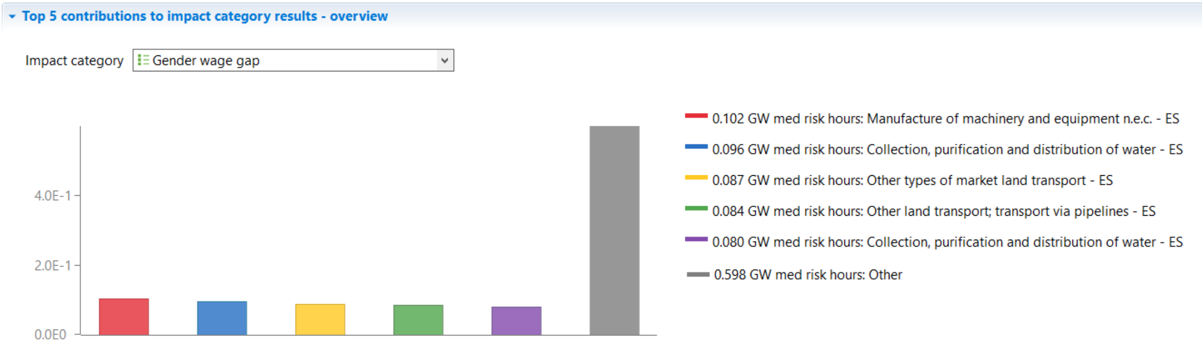

Figure 6 Results of the UHS sectors´ social performance in the Gender wage gap (GW) impact category.

And last but not least, the contribution of the sector to economic development impact category reflecting the positive risk (opportunity) of the sector demonstrates that the Hydrogen Storage in general could result in 240 moh which reflects high potential for the economy development resulting from this technology.

Figure 7 Results of the UHS sectors´ social performance in the Contribution of the sector to economic development (CE) impact category.

5. Part II - Public Perception

The second part of the Social Impact Study consisted of series or interviews conducted online with the use of Microsoft Google Forms as well as distributed via Voxco agency specialized in the internet panel surveys and gathering market data. The Part II of the Social Impact Study has been subdivided into two independent studies based on different groups of stakeholders taking part in the study. The different questionnaires have been designed and distributed to the following two groups of stakeholders and using the dedicated tools:

a) Survey dedicated to **project stakeholders** – Microsoft Google Forms
b) Survey dedicated to **general public** – Voxco database of respondents

5.1. Results

5.1.1. Results a) survey dedicated to project stakeholders

A total of 13 answers have been collected after running the online survey dedicated to project stakeholders and experts having a previous knowledge, expertise and being familiar with underground gas storage, including hydrogen. The survey contained 8 general questions of both types: open and closed, to get to know to which extent the respondents are familiar with public perception study, their previous experience related with UHS and underground gas storage projects, whether they have encountered any obstacles imposed by the public perception and negative public opinion and how these issues have been solved in the past.

The first question has been related with the interviewees´ previous experience on completing any survey or interview related with public perception of underground gas/hydrogen storage. Two out of thirteen interview had completed a similar study (Figure 8). We note that we do not know the number of underground storage projects the respondents have be involved in, but some respondents can have been involved in dozens a hundred.

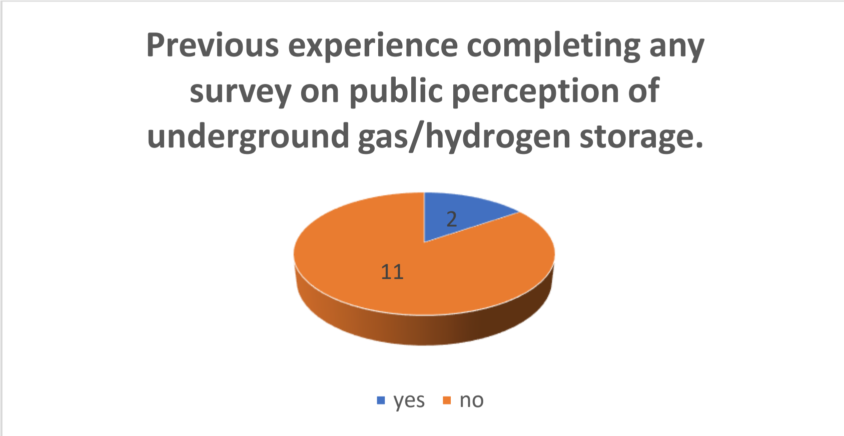

Figure 8 Result related with respondent´s previous participation in the public perception study related with UHS.

The following questions have been related with concrete cases of public perception study, materials, publications and lessons learned. It has demonstrated that the question of public perception studies and public acceptance is supported with scarce number of publications and there are still a very few experiences related with this kind of analysis.

From the previous respondents' experience there have been at least two cases observed where the construction of the new underground gas storage facility has been stopped or delayed due to the public pressure (Figure 9). Again, it should be highlighted that the total number of underground storage projects respondents have been involved in is unknown, but in some cases, one single respondent can have been involved in dozens to a hundred. This demonstrates the importance of understanding local community point of view beforehand and implementing adequate measures during the planning phase. Resulting from the further interview, it has been showed that the protests were mostly related with the concern of environmental pollution of the area in the vicinity of the planned gas storage site and concerns related with possible negative effects of the underground storage implementation in general resulting most probably from insufficient knowledge and lack of proper education related with the underground gas storage technology. This proves that a dialogue with local community, lay people, indicating possible hotspots, organization of educational campaigns and general rising of awareness is a key point for the successful new technology implementation. Moreover, the role of local authorities is essential in alleviating conflicts and possible public pressure, as well as in finding measures and solutions that could meet the requirements of both parts and prevent the project from being rejected.

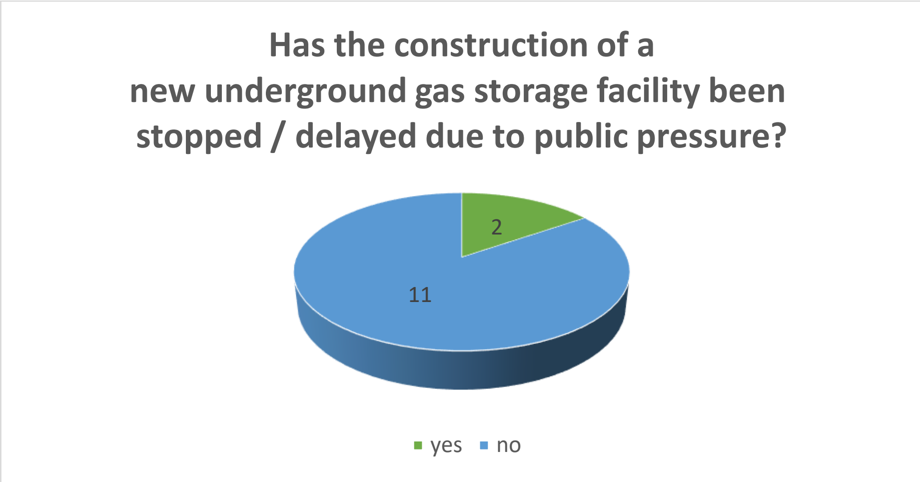

Figure 9 Result presenting the cases when the underground gas storage construction has been stopped or delayed due to public pressure.

The following questions asked to the project stakeholders and experts had the aim to highlight the key lessons learned and the best practices needed to improve the local public perception of an underground gas/hydrogen storage facility and whether those actions were successful. From the actions implemented to improve the public perception of the local community the public consultations and face-to-face engagement session have been highlighted. Those activities have resulted to be most effective way of problem solving and the elimination of uncertainty related with the implementation of underground gas storage technology. As reported, this kind of activities had an impact on the positive relations with the local residents and lead to strengthening the ties among the local community and local authorities. Additionally, it has been indicated that in some cases this kind of activities and engagement could be continuous over the whole year or period of project duration including the organization supporting community projects, volunteering, sponsorship of local sport teams etc. Further examples included various local activities aimed at environmental care and ecosystem restoration. Due to respondents´ opinion, a very important role played the dissemination of the information on the ongoing projects and the development of the activities related with the underground gas storage implementation. These activities included both online channels and social media, as well as participation in various types of events, open days at the storage facilities and fairs for the promotion of knowledge and aimed at raising awareness related with the implementation of the underground gas storage technology. Moreover, it has been highlighted that a crucial role is played by the policy and decision makers that should be actively involved into this kind of activities and be as well regularly informed on the project activities.

5.1.2. Results b) survey dedicated to general public

This section contains the answers and results of the study conducted within the group of stakeholders concerning the general public. The results have been aggregated by countries and/or total representation of the respondents from Spain, France and Germany. The results presented in this section reflect the answers provided by the respondents to questions from the three sections set in this questionnaire dedicated to general public as previously described in the Section 3.2.

Section 1) Baseline questions

The total number of respondents taking part in this study includes 322 participants from Spain (106), France (111) and Germany (105). The exact distribution of the number of respondents including male to female ratio in each of the countries selected for this study has been presented in the Figure 10. Additionally, the percentage of female and male respondents in total has been presented in the Figure 11.

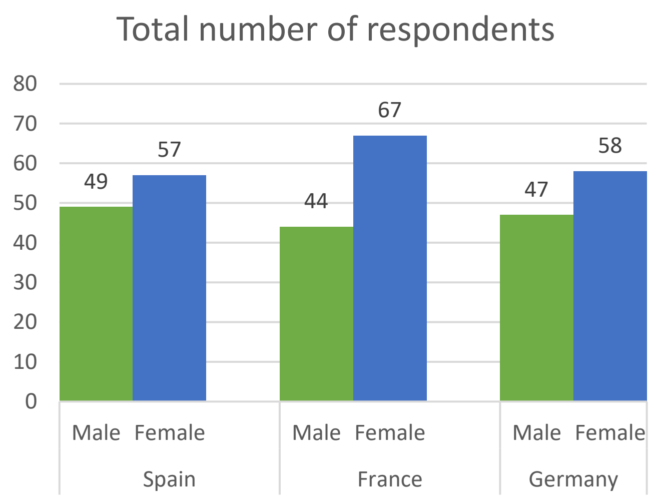

Figure 10 Total number of respondents and their distribution in Spain, France and Germany.

A similar number of respondents from each country has been selected for this study. It can be noted that for each interviewed country, there is a tendency of higher number of female responses. The total ratio of male to female responses equals 43% to 57% percent respectively as presented in the Figure 11.

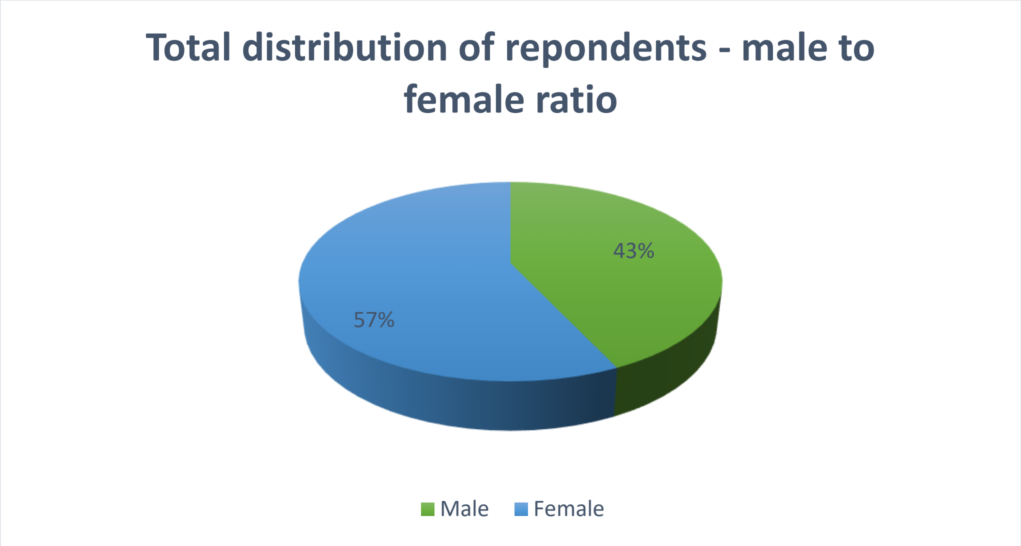

Figure 11 Total distribution of respondents representing the male to female ratio.

Additionally, this study concerns respondents of all age groups, aggregated into 6 age categories as presented below in the Figure 12. It can be seen that the highest contribution of one quarter of the total number of respondents comes from the group of respondents of 30-40 years old followed by the group of respondents of 40-50 years old equal to 23%. The third place takes the respondents aged between 20-30 representing 16% of total answers together with the group of interviewees being 60 years old and more, while the smallest contribution of 4% comes from the respondents being in the range of 15-20 years old.

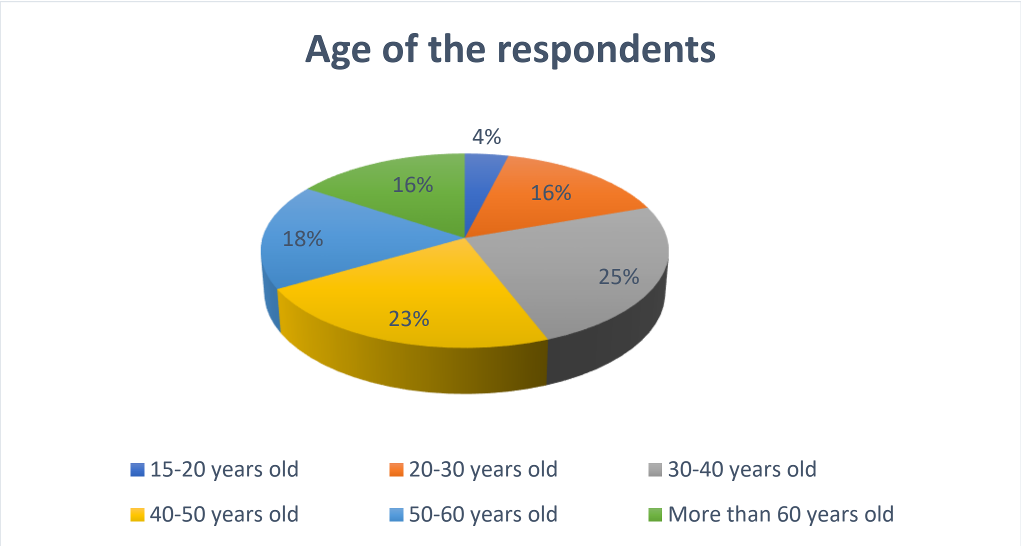

Figure 12 Age of the total number of respondents from Spain, France and Germany.

The respondents have been also asked about their level of education, where they could choose between elementary education, secondary, middle school, high school, higher education (university) or other. The results show that the highest contribution comes from respondents having just elementary education which states for 49% of total respondents. Nearly equal contributions come from respondents having high school education (18%), secondary education (16%) and middle school education (15%). Minor contribution comes from people having higher education (1%) and other (1%).

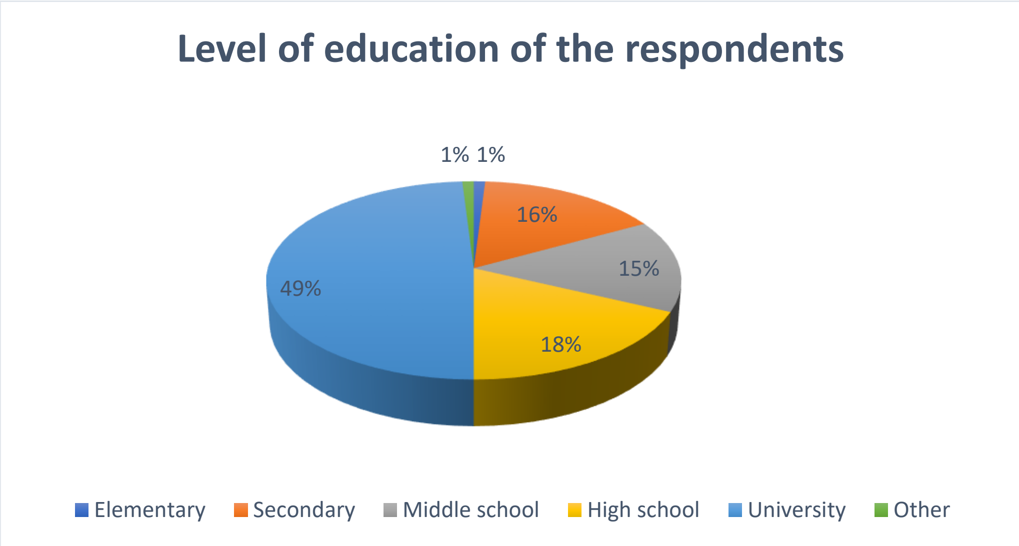

Figure 13 Level of education among the respondents of Spain, France and Germany.

This part of the questionnaire allowed for the assessment of the total number of respondents, profile of respondents, male to female ratio among respondents, their age and level of education, which will be crucial for the interpretation of the performance and answers provided in the following sections of the questionnaire related with the perception and respondents´ beliefs on the UHS.

The following results present the answers the respondents provided when asked about their interest in climate change, knowledge related with different types of renewable technologies, their beliefs regarding the renewable technologies potential in the contribution to the negative environmental impact reduction and finally their level of knowledge related with different renewable technologies including solar photovoltaics, wind energy, hydrogen technologies, hydropower, biomass and nuclear energy.

The questions to the abovementioned issues contained in the Section 1, as well as for the Sections 2 and Section 3, have been constructed in a way for the interviewees to provide the answers based on the five-point scale, where, in most of the cases, the value 0 corresponds to worst performance and 5 corresponds to best performance, unless indicated otherwise.

The results have been presented in a form of charts indicating the weighted mean value calculated according to the formula a) based on all the responses provided and furtherly graphically demonstrated on a figure reflecting five levels of performance related with each question. The performance corresponding to the issue can be categorized as: worst, bad, average, good and best. The weighted mean value obtained from the total number of answers based on a 0 to 5 scale, has been reflected on the chart by a pointer and additionally described in the description of each figure representing the consecutive questions.

a) $$\frac{\Sigma_{j=1}^{n} \cdot (x_i \cdot w_i)}{\Sigma_{j=1}^{n} \cdot w_i}$$

where,

- Σ denotes the sum
- w is the weights and
- x is the value

The first question related with the respondents´ background, previous knowledge of the renewable technologies and their interest in environmental issues has been related with the respondent interest in the climate change. The medium score was 3.7 which reflect a general good performance in this category as demonstrated in the Figure 14.

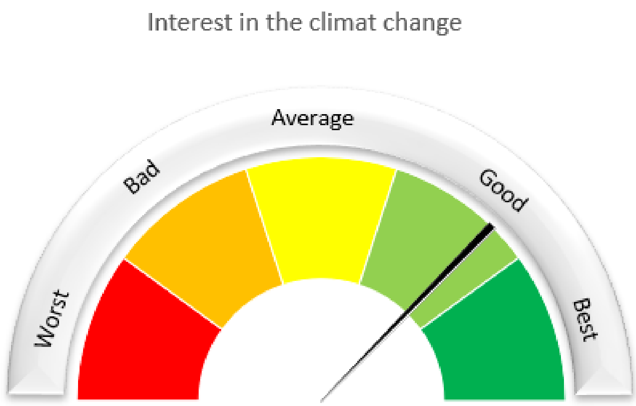

Figure 14 Rate of interest in the climate change issues. Medium score: 3.70.

The following question has been related with the general knowledge of respondents of renewable technologies in general. In comparison, the medium score for this question has been lower and equal to 3.23, however still being categorized as good general performance (see Figure 15). It should be noted that the answer provided in this survey reflect the respondents point of view and has not been supported by any further investigation. Therefore, a certain level of subjectivity should be considered.

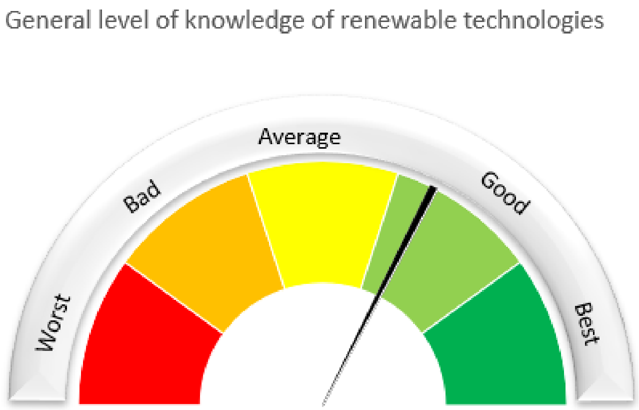

Figure 15 Level of knowledge of renewable technologies in general. Medium score: 3.23.

When asked about their beliefs regarding the contribution of renewable technologies to environmental impact reduction, the majority of respondents answered positively, stating that they see renewable technologies as an effective way to reduce negative environmental impacts. The average score was 3.39 as presented in the Figure 16.

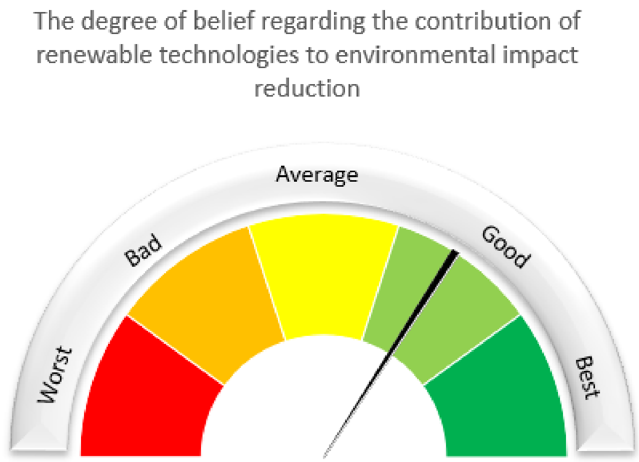

Figure 16 The degree of belief regarding the renewable technologies´ contribution to the environmental impact reduction. Medium score: 3.39.

The following question has been formulated in order to measure to which extent the respondents agree that there is a need of increasing the shares and contribution of renewable energy in the energy mix. Significantly worse performance could be observed in this category as the average score reached 3.00 points, being on the verge of the average performance as presented in the Figure 17.

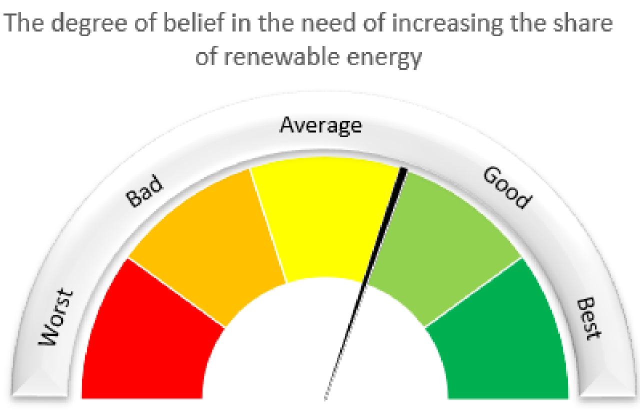

Figure 17 The degree of belief in the need of increasing the share of renewable energy. Medium score: 3.00.

A similar scenario has been observed for the question related with respondents' familiarity with the energy storage concept. The average score of 3.00 out of 5.00 has been obtained based on the total number of responses, corresponding to good performance, however being on the verge of average score (see Figure 18).

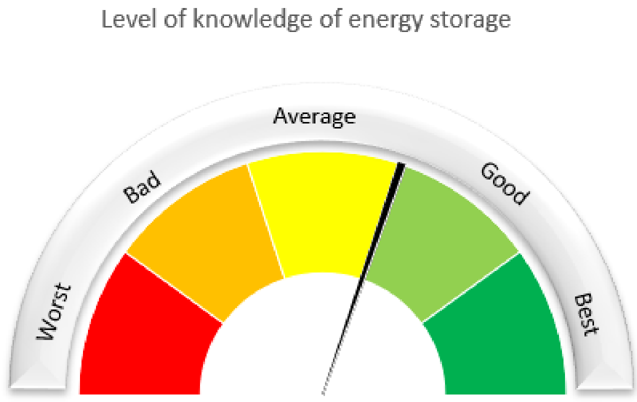

Figure 18 Rate of the general level of knowledge of energy storage. Medium score: 3.00.

When asked about their general knowledge related with hydrogen and hydrogen technologies, the respondents assessed their familiarity resulting in weighted average score of 2.73. This score corresponds to the average performance and is notably lower than the performance observed for previous questions (see Figure 19).

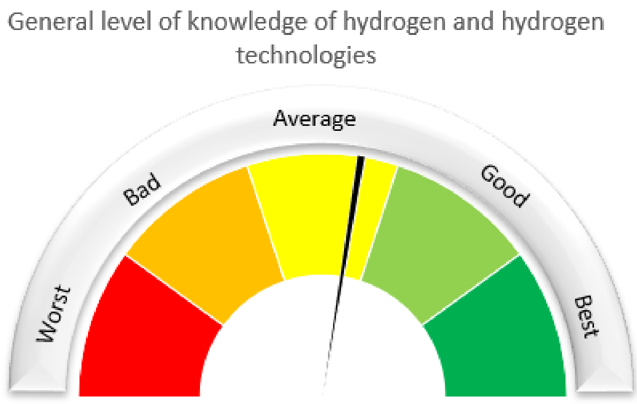

Figure 19 General level of knowledge of hydrogen and hydrogen technologies. Medium score 2.73.

The general performance for the category related with respondents' familiarity with underground storage obtained the medium score of 2.54, which categorizes as average performance. This demonstrates significant lack of knowledge related with the underground technology which might be resultant of the general level of education and certain lack of familiarity with hydrogen technologies.

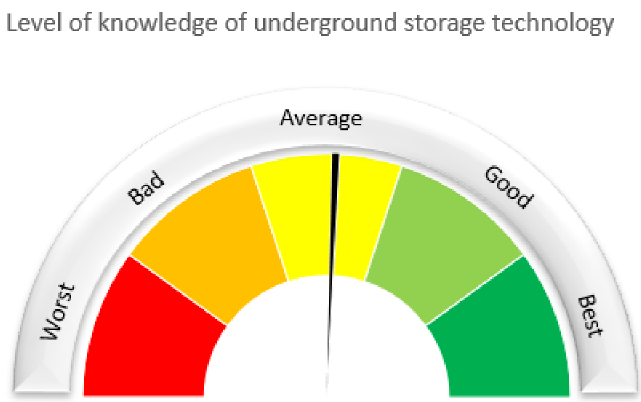

Figure 20 Level of knowledge of underground storage technology. Medium score: 2.54.

The last question from Section 1 Baseline questions has been introduced in order to compare the respondents´ level of knowledge of different renewable technologies. The interviewees have been asked on how they would rate their knowledge of such technologies are solar photovoltaics (PV), wind energy, hydrogen technology, hydropower, biomass and nuclear energy.

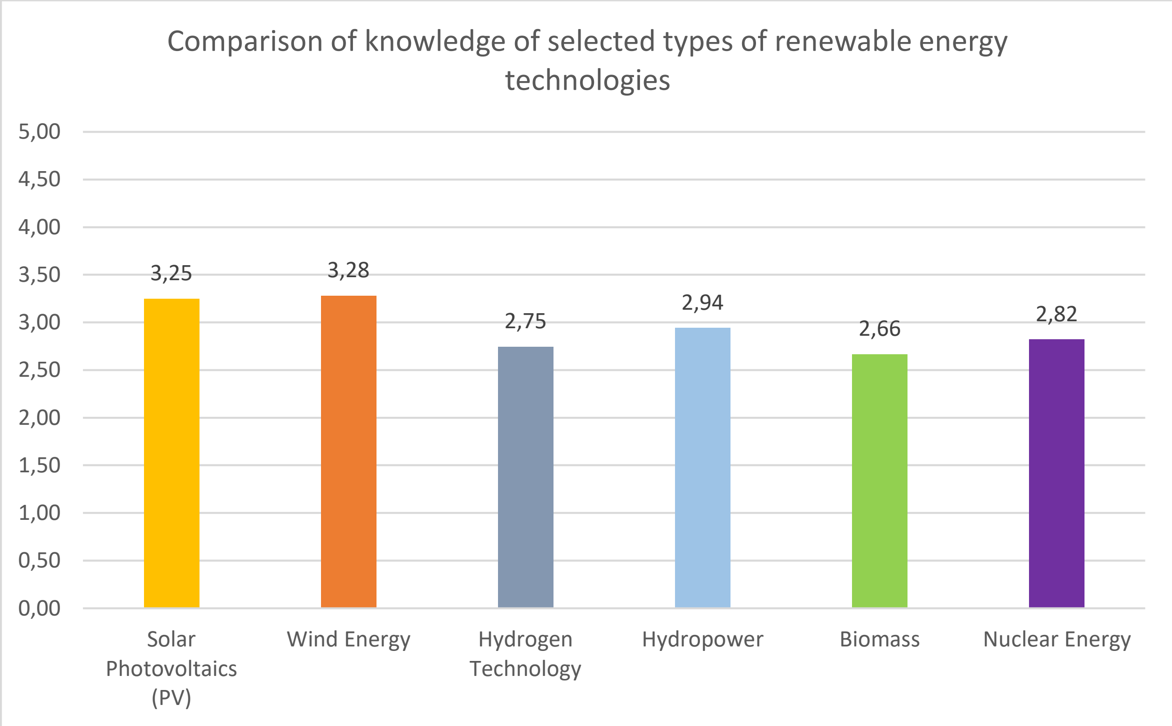

Figure 21 Comparison of level of knowledge related with selected types of renewable energy technologies.

The results presented in the Figure 21 show that the respondents declared the highest familiarity with wind energy. This might be due to the fact that this is a well-developed, relatively mature technology. The medium score was of 3.28 points. Following the wind energy, the best performance with a medium score of 3.25 has been observed for solar photovoltaic (PV) technology, which analogically to wind energy, is a fairly mature technology which is being considered as one of the most robust and popular solutions for the decarbonization of the energy sector, as well as used in households, next to wind turbines, which over last couple of years experienced a significant development together with the whole wind energy sector. Following, the hydropower technology obtained a medium score of 2,94, and a slightly worse performance of 2,82 has been observed nuclear power technology. Hydrogen technologies obtained the average score of 2.75 which additionally is coherent with the results obtained from the independent question related with respondents´ knowledge regarding hydrogen and hydrogen technologies in general. The worst performance has been observed for biomass and resulted in medium score of 2.66.

Section 2) Measuring awareness

After the preliminary analysis and the respondents´ background related with renewable technologies and their interest in sustainability and environmental issues, the Section 2 has been introduced in order to measure the respondents´ awareness focused on specific hydrogen properties and its potential applications, together with respondents´ attitude towards hydrogen and its use.

This section contained a short description and a definition of hydrogen, given the group of respondents was randomly selected and their level of knowledge might have been significantly different, thus there was a need to minimize the bias and the number of random responses and guesses. The information presented to the respondents at the beginning of Section 2 has been following:

"Hydrogen is the most abundant element on earth and is a colourless, odourless, tasteless, flammable gaseous substance that is the simplest member of the family of chemical elements. Hydrogen occurs naturally on earth only in compound form with other elements in liquids, gases, or solids. Hydrogen combined with oxygen is water (H_2O). Hydrogen combined with carbon forms different compounds—or hydrocarbons—found in natural gas, coal, and petroleum. Hydrogen is an energy carrier that can be used to store, transfer, and deliver energy produced from other sources. Hydrogen is a clean fuel that, when consumed in a fuel cell, produces only water. Hydrogen can be produced from a variety of domestic resources, such as natural gas, nuclear power, biomass, and renewable power like solar and wind. These qualities make it an attractive fuel option for transportation and electricity generation applications. It can be used in cars, in houses, for portable power, and in many more applications. Hydrogen is an energy carrier that can be used to store, move, and deliver energy produced from other sources. Today, hydrogen fuel can be produced through several methods. The most common methods today are natural gas reforming (a thermal process), and electrolysis. Other methods include solar-driven and biological processes."

The first question has been introduced in order to measure the degree of respondents´ belief in the hydrogen´s potential for environmental improvement. The medium score based on the collected answers was 3.36, corresponding to general good performance in this category (see Figure 22).

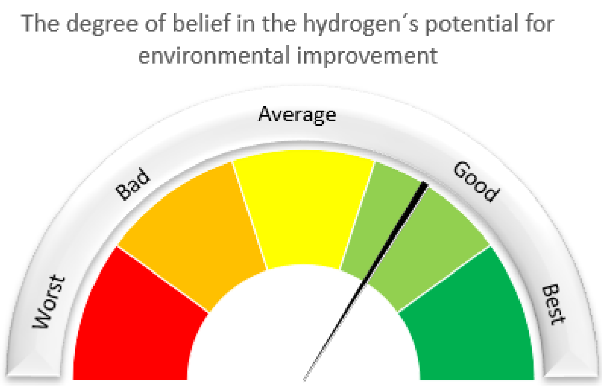

Figure 22 The degree of belief in the hydrogen´s potential for environmental improvement. Medium score: 3.36.

When asked about their attitude towards hydrogen as an alternative for conventional fuel, the respondents demonstrated a rather positive stance reaching the medium score of 3.40 which corresponds to good performance as indicated in the Figure 23.

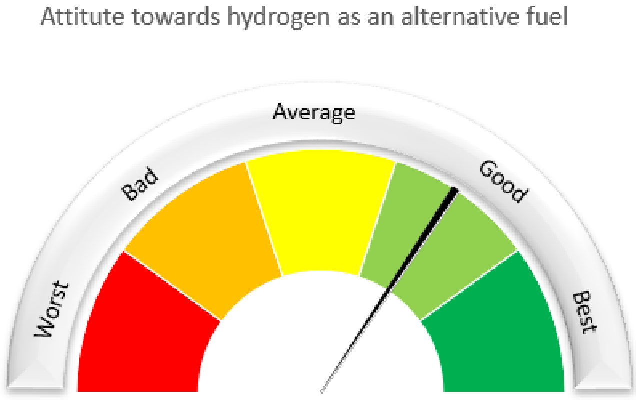

Figure 23 Attitude towards hydrogen as an alternative fuel. Medium score: 3.40.

The assessment of the respondents perception related with possible risk associated with the implementation of hydrogen as an energy vector demonstrated a slightly worse performance resulting in the medium score of 3.11. Although this result still translates to a good performance, a certain degree of insecurity can be observed compared to previous responses provided by interviewees.

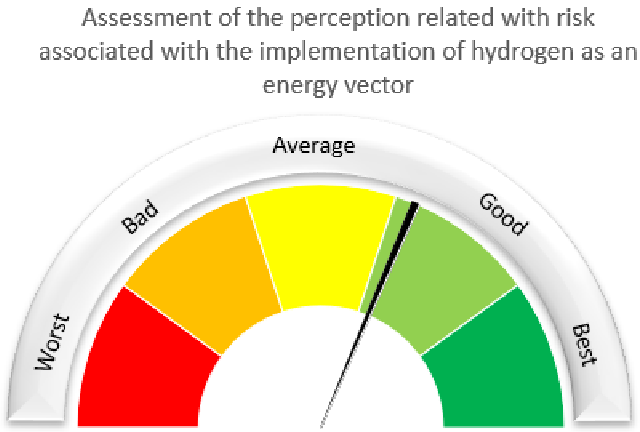

Figure 24 Assessment of the perception related with the risk associated with the implementation of the hydrogen as an energy vector. Medium score: 3.11.

The assessment of the degree of belief regarding hydrogen´s possible contribution to the reduction of reliance of fossil fuels demonstrated that the respondents tend to agree that hydrogen could have a positive effect on the reliance on fossil fuels. The medium score, demonstrating good performance was of 3.40.

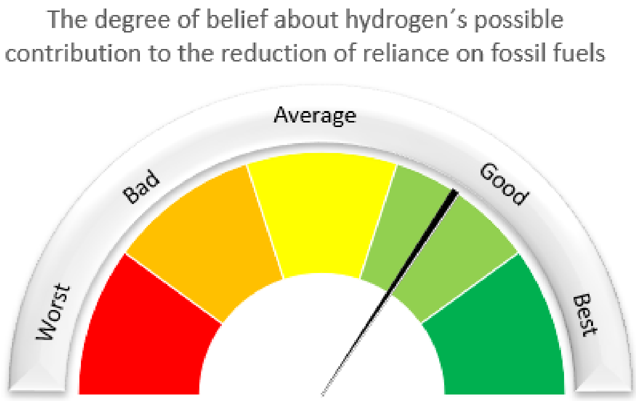

Figure 25 The degree of belief about hydrogen´s possible contribution to the reduction of reliance of fossil fuels. Medium score: 3.40.

When asked specifically about their attitude towards underground hydrogen storage, the respondents demonstrated rather good performance corresponding to the medium score of 3.22.

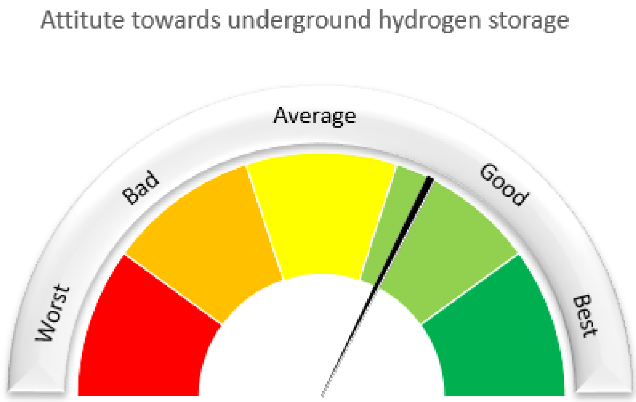

Figure 26 Attitude towards underground hydrogen storage. Medium score: 3.22.

Very similar situation has been observed in the question related with the respondents' attitude towards hydrogen storage as an alternative related with other types of energy storage (see Figure 27). It should be noted that the respondents´ perception will be strongly dependent on their level of knowledge and familiarity with the energy storage concept in general which in the Section 1 demonstrated the average performance for this category (Figure 20).

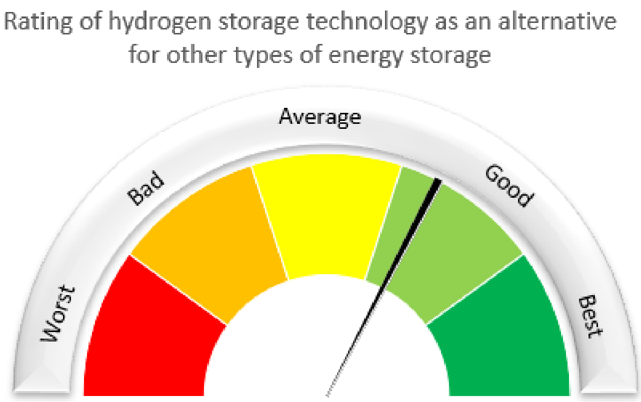

Figure 27 Rating of hydrogen storage technology and an alternative for other types of energy storage. Medium score: 3.24.

The perception related with the safety of underground hydrogen storage demonstrated some degree of uncertainty and a general good performance of the indicator, corresponding to 3.19 medium score as presented in the Figure 28. This might illustrate that the public perception of UHS in general might be related with possible fear and insecurities related with the safety of the technology, which as in previous cases might be strongly linked with the general level of knowledge of the underground gas and hydrogen storage technology.

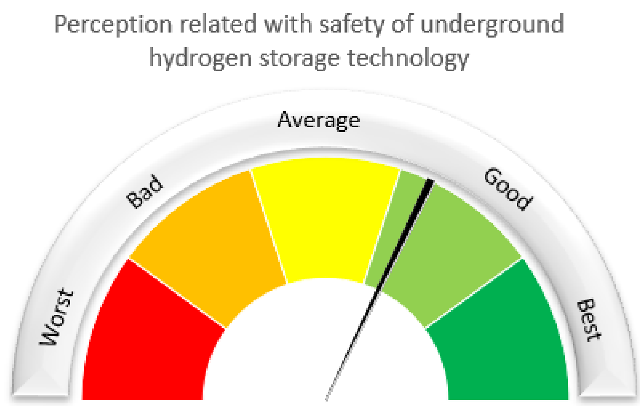

Figure 28 Perception of the safety of underground hydrogen storage technology. Medium score: 3.19.

Additionally, the respondents demonstrated their level of belief related with the UHS contribution to CO_2 emission reduction. The study showed rather positive attitude and good performance, reflected with the medium score of 3.35 (see Figure 29).

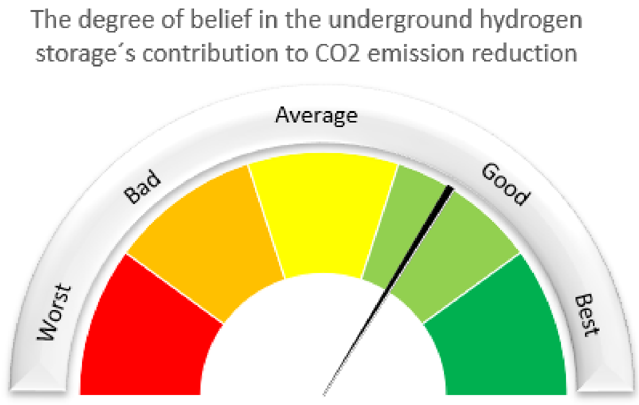

Figure 29 The degree of belief in the underground hydrogen storage´s contribution to CO_2 emission reduction. Medium score: 3.35.

The perception and the degree of respondents' belief regarding the UHS potential contribution to increasing the security of the European energy system demonstrates generally good performance, with a medium score of 3.28 as presented in the Figure 30.

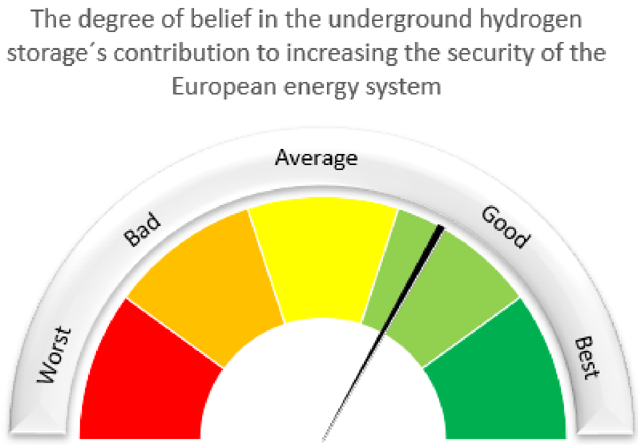

Figure 30 The degree of belief in the underground hydrogen storage´s contribution to increasing the security of the European energy system. Medium score: 3.28.

Section 3) Influencing factors

The third section of the questionnaire dedicated to the general public and lay people not having previous experience related with hydrogen technologies and underground gas storage solutions serve to identify possible factors that might be influencing their attitude towards the implementation of the aforementioned technology and their general opinion.

As in the Section 2, before proceeding to the questions defined in the Section 3, the respondents have been provided with short information related with hydrogen storage technology. The information contained in the Section 3 was as follows:

"In simplest terms, energy storage enables electricity to be saved for a later, when and where it is most needed. Energy storage will become more important because renewable energy sources such as wind and solar are not always available when needed. Hydrogen can be produced by splitting water with renewable electricity via a process called electrolysis. As a fuel, hydrogen can be used in vehicles and to produce heat and electricity for industry and buildings. It can also be stored underground in large quantities for a long time to be used later when needed. Hydrogen is already stored underground in salt caverns in a few places in the United Kingdom and the United States, but these sites have not been tested to see if hydrogen can be rapidly injected and extracted as wind and sunshine vary. Hydrogen could be stored in gas fields but there is little experience of this option. Hydrogen storage would, technically, be very similar to natural gas storage. In Europe, more than 20% of the annual gas consumption is stored underground, enabling to cope with a highly seasonal demand, and acting as a strategic reserve against possible ruptures of the importations. For Hydrogen, underground storage would enable coping with a highly fluctuating production of green hydrogen, and still act at a strategic reserve, by having the fuel of the energy system stored within the country. While hydrogen has many benefits, it is also considered a rather difficult medium to be stored. The biggest challenge in storing hydrogen results from its properties, being its low density and the smallest molecular weight from all chemical elements. This causes problems with storage tightness in tanks or underground and the low gas density means that it occupies large volumes of requires a lot of power to be compressed."

The first question has been related with the respondents' perception about the negative influence of traffic during the construction phase of the UHS. In case of this question, a reversed scale has been adopted as presented in the Figure 31, where 0 corresponded to the best performance and thus no negative impact of the possible traffic, while 5 indicated the worst performance related with high possibility of negative traffic impact according to the interviewees´ perception.

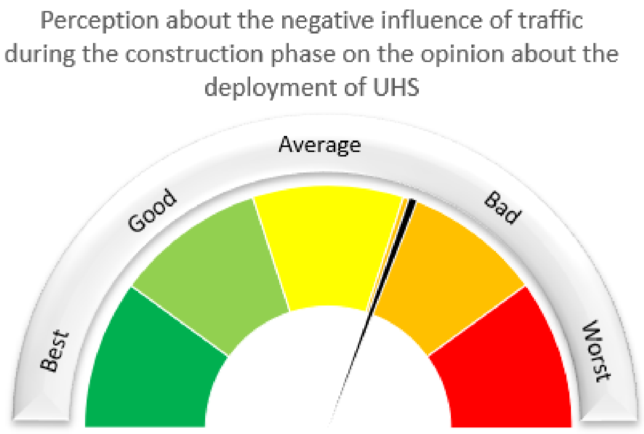

Figure 31 Perception about the negative influence of traffic during the construction phase on the opinion about the deployment of underground hydrogen storage. Medium score: 3.04.

The results demonstrated certain degree of uncertainty and rather negative performance based on respondents´ view. The obtained score was of 3.04 reflecting bad performance, however being on the verge of average. Nevertheless, this question should be considered as a certain hotspot and possible problematic issue for the implementation of the underground gas technology.

On the other hand, the following issue has been related with the respondent´s perception of the UHS´s contribution to the noise pollution during its normal operation. As in the previous case, the reverse scale has been applied, meaning 0 indicated the best performance and 5 the worst. It can be seen, that analogically, rather bad performance has been observed corresponding to the medium score of 2.96 as can be seen in the Figure 32.

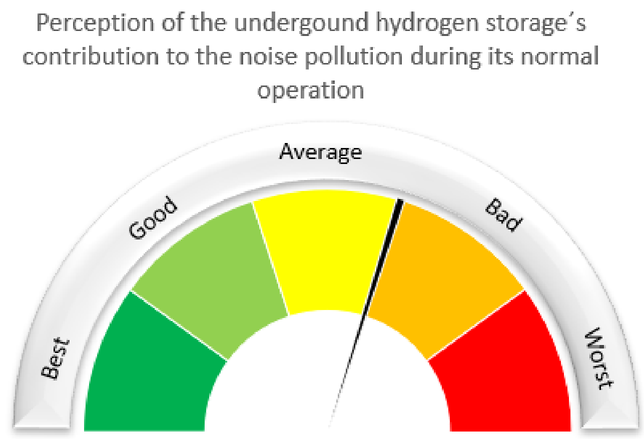

Figure 32 Perception of the underground hydrogen storage´s contribution to the noise pollution during its normal operation. Medium score 2.96.

Those results demonstrate that possible noise pollution related with the construction and operation of the UHS can be the factor influencing the public opinion and can be a reason for possible public pressure.

Next question has been introduced in order to assess the respondents´ general uncertainty regarding underground hydrogen storage, after being presented the additional information provided at the beginning of the Section 3. Despite the information provided, the performance and the degree of uncertainty related with UHS technology achieved a medium score of 3.07 corresponding to relatively good performance (see Figure 33).

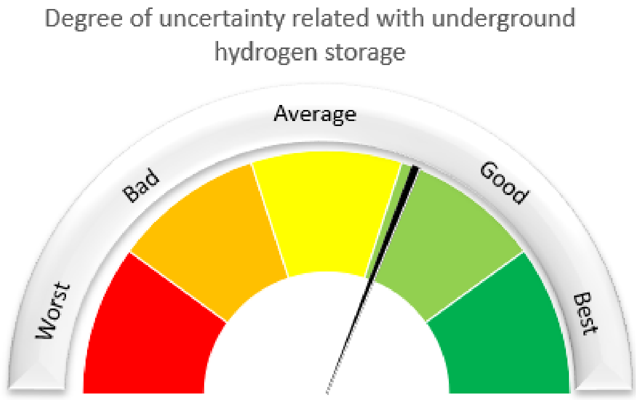

Figure 33 Degree of general uncertainty related with underground hydrogen storage. Medium score: 3.07.

When asked about their perception connected with the UHS potential for job creation, most of the respondents demonstrated their positive attitude believing that UHS might contribute to the increase of employment and creation of new opportunities. This result corresponded to the medium score of 3.24 and demonstrated good performance as can be seen in the Figure 34.

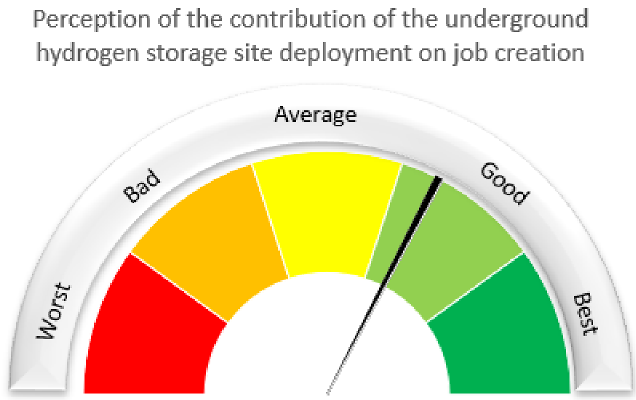

Figure 34 Perception of the contribution of the underground hydrogen storage site deployment on job creation. Medium score: 3.24.

Last question concerning the Section 3 and thus the possible influencing factors has been related with the respondents´ willingness to live in the vicinity of the UHS. The results showed sceptic respondents´ attitude resulting in a medium score of 2.79 and average performance (see Figure 35). This proves the pattern and a commonly observed phenomenon, commonly referred to as “Not In My Backyard” syndrome, reflecting the negative perception towards a new development to be introduced in the residents local area. This situation is commonly observed, as it has been also in the case of Keuper Gas Storage Project project, as it has been indicated during the bilateral consultation between Aragon Hydrogen Foundation, Geostock and INEOS Inovyn representatives, being a part of the study preparation [9]. Keuper Gas Storage Project includes the construction and operation of 19 underground cavities with capacity to store a working gas volume up to 500 million standard cubic metres (mcm) of natural gas, having an import and export capability of up to 34 mcm per day. The Keuper Gas Storage Project (KGSP) involves using specially designed underground salt cavities – created through solution mining – to store gas. The project was granted a Development Consent Order in 2017, (however, despite being consented, it was not built). Later on, in 2020 the KGSP started on a programme of work to expand the definition of “gas” to include also hydrogen and therefore to convert to hydrogen storage. Having completed the internal studies, FEED study and cavern subsurface study for hydrogen, KGSP embarked on a programme of public consultation before submission of the amendment. The non-statutory public consultation took place between October and November 2022, followed by submission of change application to Government. Despite carrying out various activities and contacting with large number of people, the amount of feedback was rather poor, however no actual objections raised and mostly positive answers have been registered indicating the respondents´ belief in the need for decarbonization. Based on this study results that people do not seem overly concerned about hydrogen storage as against natural gas storage for a given facility. Additionally, the study shows that whilst stakeholders and local community might not be happy with construction disruption and a new development, hydrogen safety is not considered seemingly worse than natural gas [10].

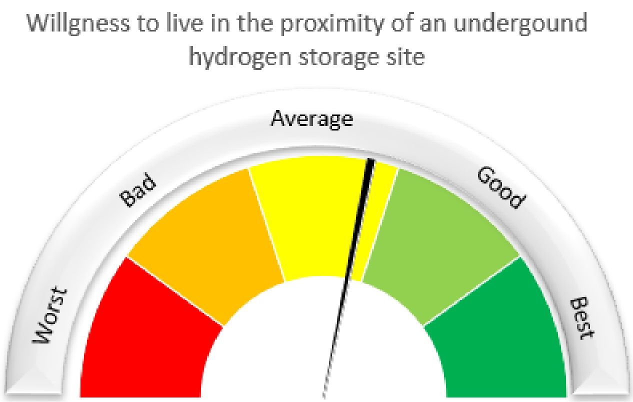

Figure 35 Willingness to live in the vicinity of underground hydrogen storage site. Medium score: 2.79.

5.2. Analysis

The survey dedicated to general public has been distributed to randomly selected sample of more than 300 respondents from all age categories, education levels and sexes from three countries considered under Hystories project being Spain, France and Germany, inter alia. The results gathered within the study dedicated to general public demonstrate strong relation between the public perception of the hydrogen technology and UHS and the level of education. Most of the respondents resulted to have elementary education level, which might have had an impact on their perception and comprehension of renewable technologies including UHS and its application.

It has been observed that most of the answers corresponded to the results between the medium value of 2.50 and 3.70 demonstrating relatively neutral attitude and corresponding to average/good performance for the selected categories.

No specific improvement in the performance have been observed for parts 2 and 3 in which the respondents´ have been provided with additional information related with hydrogen, hydrogen technology and underground gas storage concept.

The highest medium score has been obtained when the respondents have been asked about their interest in climate change corresponding to 3.70 medium score.

The lowest medium score has been observed for questions related with the respondents´ level of knowledge of underground storage technology resulting in 2.54 medium score.

6. Conclusions

The social impact study has been introduced to analyse the underground hydrogen storage potential social impact and the public perception by running social hotspot analysis and a series of surveys dedicated to lay people as well as experts having previous knowledge of UHS.

The hotspot analysis showed that the sectors and processes from Spain connected with the highest potential social risk include construction, manufacture of machinery and equipment as well as collection, purification and distribution of water and land transport including transport via pipelines. Those sectors might contribute negatively to such social impact categories as fair salary, gender wage gap and to some extent to the risk of fatal accidents. The underground hydrogen storage developed in Spain shows general high opportunity regarding the possible economic development resulting from implementation of this technology. Nevertheless, it should be taken into account that the product´s performance in terms of social impact is strongly dependent on the location, the process´ intensity and the general level of risk or opportunity associated with given process and thus its characteristics in terms of negative or positive social performance.

The study conducted on the sample involving experts and project stakeholders familiar with hydrogen technologies and having previous experience, despite relatively low occurrence, corresponding to 2 out of 13 answers based on the survey conducted with project stakeholders, proved that there have been some cases where the deployment of underground hydrogen or gas storage sites have been affected by public pressure. The number of projects the 13 respondents have been involved in is however not known, but is likely several hundreds. This has been mainly due to insecurity regarding possible negative effects of the new technology deployment and the local community preoccupation for environment. The survey allowed to gather the key best practices and lessons learned as well as recommendations to alleviate the risk of possible delays or termination of project of similar character due to negative public opinion. The dialogue with local community, promotion and dissemination actions as well as general rising of the awareness of public and local community have been indicated as key measures that could prevent the possible negative consequences of public pressure and ensure successful underground hydrogen/gas storage site deployment.

Additionally, the results of the study conducted on the group of people representing general public, not necessarily having the technical knowledge, that the biggest concern results from the deployment of new underground hydrogen technology in the vicinity of local community resident area. This is due to the common social phenomena referred to as "Not in My Backyard" syndrome which characterizes by the fact that people might be positive about some certain technology, however their attitude would change dramatically if this technology would to be implemented near their place of residence. Those results show the strong need to promote the hydrogen technologies among lay people and rising their consciousness related with energy storage. Special attention should be paid to increasing knowledge of underground hydrogen storage in salt caverns and porous media and its possible positive and negative effects on the society and local community including such factors as safety, pollution, opportunities including the job creation and general economic development.

7. References

[1] Weeda, M., and M. de Best-Waldhober. "Public perception of hydrogen storage." (2013).

[2] UNEP, 2020. Guidelines for Social Life Cycle Assessment of Products and Organizations 202 Benoît Norris, C., Traverso, M., Neugebauer, S., Ekener, E., Schaubroeck, T., Russo Garrido, S., Berger, M., Valdivia, S., Lehmann, A., Finkbeiner, M., Arcese, G. (eds.). United Nations Environment Programme (UNEP).

[3] Valente, Antonio. "Advances in life cycle sustainability assessment of hydrogen energy systems." (2020).

[4] https://nexus.openlca.org/database/PSILCA

[5] Benoit, Catherine, and Bernard Mazijn, editors. Guidelines for Social Life Cycle Assessment of Products: A Social and Socio-Economic LCA Code of Practice Complementing Environmental LCA and Life Cycle Costing, Contributing to the Full Assessment of Goods ar Services within the Context of Sustainable Development. United Nations Environmental Programme, 2009.

[6] Ciroth, Andreas, and Franziska Eisfeldt. "PSILCA—a product social impact life cycle assessment database." Database version 1 (2016): 1-99.

[7] Andrews, Evan Stuart. Guidelines for social life cycle assessment of products: social and socio-economic LCA guidelines complementing environmental LCA and Life Cycle Costing, contributing to the full assessment of goods and services within the context of sustainable development. UNEP/Earthprint, 2009.

[8] Mancini, Lucia, et al. "Social assessment of raw materials supply chains." European Comission: Brussels, Belgium (2018).

[9] Keuper Gas Storage Project "Consultation Report" November 2015 http://www.kgsp.co.uk/wp-content/uploads/2015/12/5.1-KGSP-Consultation-Report.pdf

[10] Keuper Gas Storage Project "Consultation Report" January 2023 https://www.kgsp.co.uk/wp-content/uploads/2023/02/KGSP-Consultation-Summary-January-2023.pdf

Hystories project consortium

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