Ansorena Ruiz *et al.*
Energy, Sustainability and Society (2024) 14:31
https://doi.org/10.1186/s13705-024-00466-z

Energy, Sustainability and Society

RESEARCH

Open Access

Understanding stakeholder attitudes towards low-head pumped hydro storage technology

Ruben Ansorena Ruiz[1*], David Schürenkamp[1], Jeremy D. Bricker[2,3], Madita Olvermann[4] and Nils Goseberg[1,5*]

Abstract

Background The share of renewable energy feeding the European grid has been growing over the years, even though the intermittency of some renewable energy sources can induce electric grid instability. Energy storage has proven to be an effective way of reducing grid instability. Various solutions for large-scale energy storage are being researched nowadays. This study focusses on the innovative low-head pumped hydro storage (LH PHS) technology, a large-scale energy storage scheme suitable for shallow seas (5 – 30 m depth). Implementation of renewable energy technologies, such as wind farms in Europe, Asia and North America, has faced public opposition which has delayed or even cancelled the implementation of renewable energy projects. Literature about public perception of projects highlights the importance of involving stakeholders from the early stages of project planning. Considering this, the present study aims to collect stakeholder opinions (via an online survey) to determine what is necessary for a smooth implementation of LH PHS in the North Sea, both from technical and policy points of view.

Results Stakeholders from commercial parties, government authorities and local groups recognized the potential of LH PHS as a means to increase the share of renewable energies within the European power grid. Economics, bureaucratic burden, and structural safety have emerged as primary aspects of concern respecting the implementation of LH PHS. The impression of the respondents is that a low-head pumped hydro station would not have negative effects on their organizations. Furthermore, most of the engineering firms participating in the study communicated that their knowledge and resources could be involved in the construction of such an energy storage facility.

Conclusion As identified stakeholder concerns such as economics and structural safety are currently being researched, effective communication of the findings of this research is paramount to keep stakeholders informed of the ongoing progress. Two-way communication between researchers and stakeholders is recommended to enhance public acceptance of future technologies. Furthermore, is it advisable to undertake an examination of the available energy policies relevant to LH PHS.

Keywords Pumped hydro storage, Social acceptance, Stakeholder analysis, Stakeholder opinions, Energy storage, Energy policy

*Correspondence:
Ruben Ansorena Ruiz
r.ansorena-ruiz@tu-braunschweig.de
Nils Goseberg
n.goseberg@tu-braunschweig.de
Full list of author information is available at the end of the article

Background

The European Union aims to achieve climate neutrality by 2050 [1]. Renewable energy generation has been increasing over the last years, partially as a result of more ambitious climate goals and partially due to its reductions in cost [2]. Amongst available technologies for renewable energy production, wind and solar power have become especially widespread, with a promising path of market penetration within and outside of Europe [3].

However, renewable energy generation is variable and unpredictable throughout the day and within the annual meteorological cycle [4, 5]. The intermittency of wind and sun availability translates into electricity generation unpredictability, which poses difficulties for matching demand and generation. Such mismatch makes an electric power system unstable. This, in turn, could result in failure to supply electricity when necessary, or, in the worst case, power blackouts. Additionally, the synchronous generators of conventional power plants (coal, oil, nuclear, gas, hydro) are able to provide inertia, frequency and voltage stability to the energy grid due to the large rotatory masses of their generators and their ability to increase or reduce their power generation to match demand for power [6]. This dispatchable power has historically ensured the flexibility of the power system, and has been necessary to cope with the uncertainty and variability of electric demand and generation [7]. However, nowadays power electronic interfaced devices can provide inertia, frequency and voltage stability without the use of large rotatory masses [8].

The introduction of stochastic renewable energy sources such as wind and solar power reduces the flexibility of the energy grid and thus grid stability is at risk [7, 9]. As an example, Johnson et al. [10] determined via simulation that removal of nuclear power plants in the electric grid of Texas, for a 30% renewable energy generation scenario, required the activation of coal and natural gas-combined-cycle plants to maintain stable system inertia. It is clear that intermittent and fluctuating renewable energy generation requires the support of other technologies [11]. Large-scale energy storage presents itself as a great alternative since it both increases energy storage and the hydraulic synchronous generators can provide inertia to the system [11–13].

Nowadays, the most common and proven energy storage technology applied at utility grid scale is pumped hydro storage [13]. It utilizes the natural elevation differences present in mountainous regions to store surplus grid electricity generation as potential energy, by pumping water to an elevated reservoir. When the electric demand exceeds that available in the grid, the stored water can be released to a lower reservoir, driving turbines to generate electricity in the process. Rogner and Troja [14] estimated that 94% of worldwide energy storage is carried out using pumped hydro storage (PHS) technologies. Furthermore, they showed that PHS is an economically and technologically viable solution for reducing peak loads and storing wind and solar energy to ensure power quality. However, lowland regions across the globe will for a foreseeable time in future remain unable to benefit from the grid stabilization services of PHS; European countries such as coastal Belgium, Denmark, the Netherlands and the northern part of Germany cannot make use of conventional pumped hydro storage. This challenge has led to the ambition to provide storage capacity even for flat topographies, where low-head pumped hydro storage (LH PHS) technology is a promising option [15], especially at sites where geology does not make underground PHS [16] or compressed air energy storage feasible. LH PHS technology employs the same principle as mountainous PHS; however, there are no mountain reservoirs. Instead, a large impermeable dike forming a circular reservoir should be built in a shallow sea (depth between 5 and 30 m), resulting in the creation of an enclosed salt water body on the inner side of the dike. When there is surplus grid electricity generation, it is used to pump salt water out of the interior of the reservoir, reducing its volume and, consequently, lowering its water surface elevation. This action creates a head difference relative to the sea surface. When electricity is needed (demand for electrical power in the grid exceed generation), salt water from the sea flows downward into the reservoir, driving turbines to produce electricity [12, 15, 17]. For mountainous PHS, the head difference is created by the large height difference between the lower and upper reservoir (hundreds of meters of head) whereas for LH PHS the head difference is created by the action of pumping out the reservoir and thus lowering its water level (tens of meters of head). For the sake of clarity, Fig. 1 shows a schematic of a LH PHS plant. Conceptually, LH PHS requires more space than PHS because of the larger discharges used for operation. As space is occupied for human use purposes, any planning, permitting and implementation requires careful interaction with stakeholders and society at large. Failure to include relevant parties and stakeholders has been proven to add hurdles and roadblocks to implementation of major infrastructure projects in the past, not only in the energy sector, as demonstrated in the following paragraph [18–20].

Experience from previous renewable energy technologies showed that wind projects have encountered opposition from local inhabitants during and after construction of wind parks [21–25]. Solar power has also faced similar issues. Jobert et al. [26] recommend the inclusion of stakeholders in the planning stage of wind and solar power plants to increase acceptability of the technologies

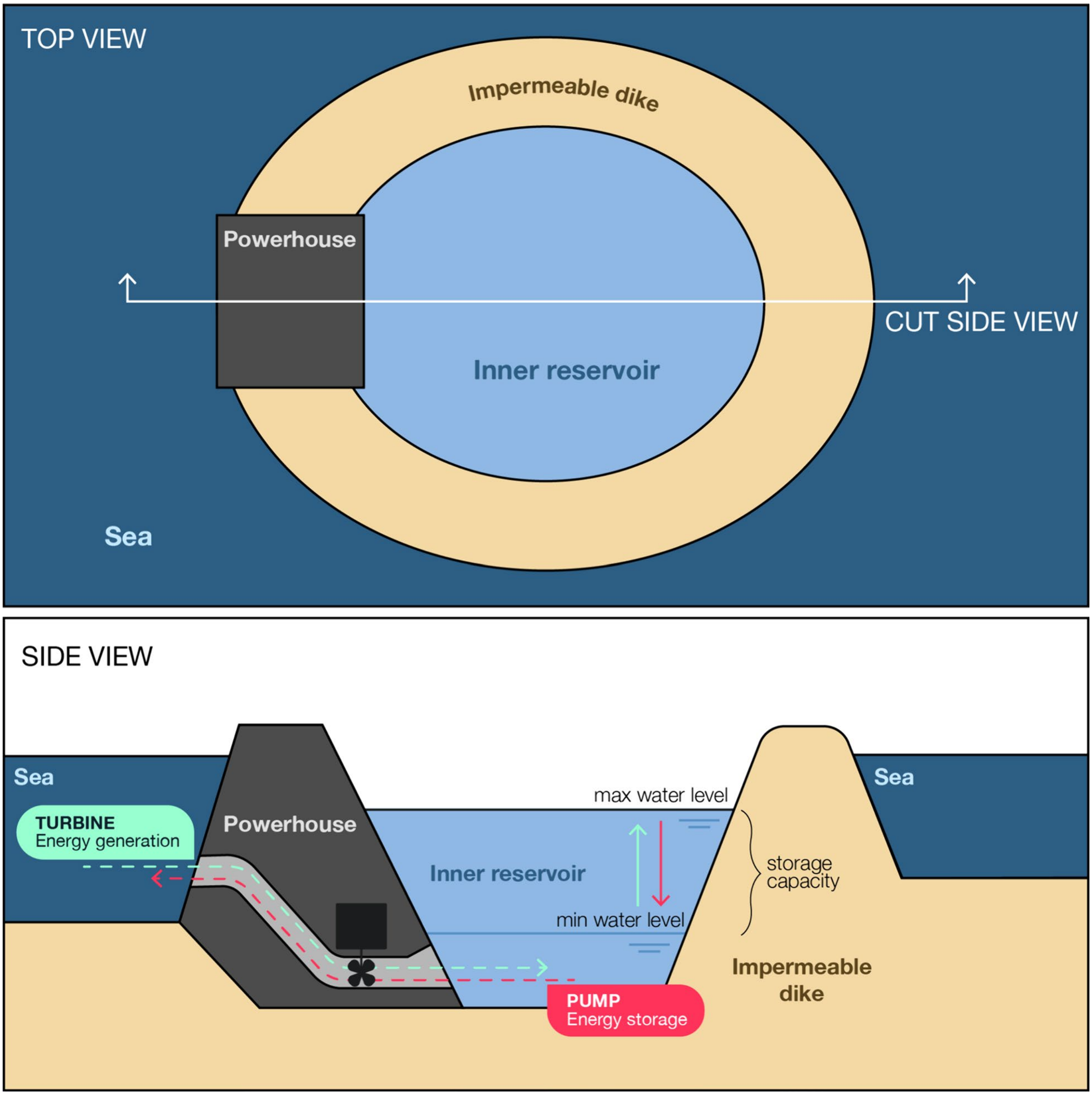

Fig. 1 Schematic of a LH PHS plant showing a top view and a cross section view. The cross section view shows how the water level in the inner reservoir decreases when pumping and how it increases when turbining. Notice that the available head is the difference between the sea water height and the inner reservoir's water height

within communities. Likewise, interviews carried out at the coast of Mutriku (Vasque Country, Spain) for a coastal wave energy plant found that information about the project and participation of the local residents is a key for acceptance [27]. Similarly, so-called mega-projects have been followed by opposition and contestation [28]: within the Stuttgart 21 project, citizens demonstrated against the demolition of 100-year old tress and after being forced out aggressively by the police, these works were put on hold. Issues included insufficient transparency during stakeholder negotiations. Additionally, not much room for project modification was given, so the stakeholder participation was merely used as a way of sharing the project as it was planned [29]. Considering these lessons, a LH PHS project must involve stakeholders beginning at the early stages of its research to include non-technical considerations within the design that increase acceptability for the general public. Along this line, an acceptance study was carried out on Guernsey island (located in the English Channel) before the installation of an offshore wind farm. That study found that the use of local resources for the construction and then local consumption of renewable energy enhanced community acceptance of offshore wind parks. The study also found a variation of acceptance depending on the location of the future wind farm [30].

The above examples of (mega-)projects and their stakeholder relations have largely motivated this work that, for the first time, investigates future stakeholder opinions in response to the novel LH PHS technology, at a stage long before the implementation phase. The LH PHS technology is currently under scientific and commercial development, though still at an early stage. This work however aims to start stakeholder communication at the earliest possible stage within the technology evolution timeline and thus, engagement has been initiated while the technology is still being researched. Due to the innovative nature of LH PHS technology, there isn't any available literature on questionnaires or stakeholder meetings incorporating stakeholder opinions towards this specific technology, yet. The overall objective of this work is to gauge opinions, interest and objections of stakeholders with respect to novel LH PHS energy storage development in the North Sea.

The primary objective of this work is to examine stakeholder opinions regarding LH PHS development in the North Sea. The specific objectives include:

- To identify challenges, hurdles and obstacles for the implementation of LH PHS that potential stakeholders may have.
- To elaborate on risk factors perceived by stakeholders.
- To investigate potential redlines with respect to the location of LH PHS.
- To identify what research topics stakeholders are most concerned about.
- To investigate if companies have the resources and knowledge for manufacturing a LH PHS plant.

The stakeholder opinions can be turned into design requirements which, as shown from previous literature described in this section, increases future stakeholder acceptance. Furthermore, the stakeholder concerns must be addressed, and regular two-way communication between project developers and stakeholders must be maintained over time.

Methods

A sequence of tasks was required to obtain data through a stakeholder survey; these are described in the present chapter. The work is started by describing the process by which stakeholders, i.e. questionnaire participants, were identified and contacted. Next, the development of a questionnaire along with its goals is described.

The questionnaire included both quantitative and qualitative questions and it was available online for the contacted stakeholders. Additionally, the access link to the online questionnaire was published through multiple advertisement campaigns on social media, which led to additional non-targeted participants who found the survey (ALPHEUS LinkedIn page,[1] ALPHEUS twitter account[2] and ALPHEUS webpage[3]). The stakeholder survey ran from the 15th of November of 2021 until the 23rd of March of 2022. All survey questions and anonymized answers are publicly available here: 0.24355/dbbs.084–202301101711-0.

Stakeholder identification

A stakeholder analysis starts with a dedicated stakeholder identification process. To that end, a clear definition of the term stakeholder was derived. Freeman [31] was the first author to define a stakeholder approach with his book "Stakeholder Management: A Stakeholder Approach" [31]. He defined stakeholders as "any group or individual who can affect or is affected by the achievement of the organization's objectives". He received much criticism for his broad definition of "stakeholder" and since then, several other authors have provided different definitions for "stakeholder" [32–35]. The definition of "stakeholder" is adjusted for each specific analysis. Thus, the present study defines a stakeholder as: "any person, group or organization that is directly or indirectly affected by the development of a low-head pumped hydro storage plant in the North Sea". With this definition the spatial focus is put on the North Sea. This site is chosen due to its shallow depth which shows potential for LH PHS [15, 17, 36]. Furthermore, the installation of a large amount of offshore wind power [37] shows additional potential for the development of LH PHS [15].

A large LH PHS project could potentially affect a large number of groups and individuals. To limit the amount of identified stakeholders [38], the focus of this work is narrowed to three different stakeholder subgroups, as a subentity of the previous stakeholder definition. These are:

[1] lnk.tu-bs.de/0FgQqk.

[2] https://twitter.com/AlpheusH2020/status/1478749873872723973.

[3] https://alpheus-h2020.eu/.

1. Commercial parties interested in potential LH PHS sites (energy distribution companies, turbine manufacturers, etc.): individuals in this group are those possessing the technical expertise required for the design, construction and grid integration of a LH PHS plant. Furthermore, they could be affected by economic benefits and know-how from participation in such a project.
2. Government authorities/policy and decision makers on spatial planning and permits: individuals in this group are those in charge of drafting and approving legislation that could impact the development of a LH PHS project. It also includes individuals that would oversee the approval processes for the construction and operation of a LH PHS project.
3. Local coastal communities and their interest groups (fisheries, nature protection groups, tourism associations, etc.): individuals in this group are those habituating or having regular non-business activities along the coast and nearshore area of the North Sea.

For the purpose of clarity, the aforementioned terms will be referred to as follows for the remainder of this manuscript: (1) “commercial parties”, (2) “government authorities”, (3) “local groups”.

Limiting the identification of stakeholders may cause omission of important ones [39]. However, the three identified subgroups provide a large range of stakeholders, including the most relevant stakeholders for a LH PHS project. As per the overall objective of this study and bearing in mind the emerging character of LH PHS, the chosen approach allows a more fine-tuned response of relevant stakeholders at the stage of development that LH PHS technology has currently reached.

Since there is no universal procedure for stakeholder identification, this process has been conducted in various ways in previous literature [32, 40, 41]. Based on existing methods (use of expert opinions, focus groups, semi-structured interviews, snowball sampling [42]), the procedure for stakeholder identification in the present analysis was carried out via the following steps:

1. An initial “draft list” was developed by a selection panel of experts and scientists (from the ALPHEUS project consortium) involved in the development of LH PHS technology. The list included 53 different stakeholders, grouped into different sectors such as civil engineering, manufacturing, energy generation, energy distribution, government, etc.
2. The original “draft list” was enlarged with the identification of more stakeholders into a so-called “initial stakeholder list”. Enlarging the original list was carried out by the research team. The chosen approach, i.e., identification of additional stakeholders by only the research team, could imply some kind of bias that was dealt with, separately. To that end, the “initial stakeholder list” was distributed to other experts within the ALPHEUS project consortium. This development group consisted of other experts from various nationalities and educational backgrounds. These multidisciplinary and multinational aspects of the control group approving the updated initial stakeholder list ensured having a stakeholder list with multiple entry points and thus reduced bias from the initial group elaborating the list. Completion of step 2 yielded an “initial stakeholder list” with 177 stakeholders, an increase of 334% over the draft list.
3. It could be argued that the stakeholder list after step 2 is still biased by the development group and its knowledge of LH PHS technology. Therefore, to reduce the remaining bias, two further actions were taken to limit the bias that may still exist. On the one hand, the stakeholder questionnaire (see Sect. Description of the questionnaire) was shared via the social media pages of the development group (see Sect. "Methods"). The goal of this first action was to reach as many interested stakeholders through shared networks and interest networks as possible using the power of social media [43–45]. To avoid responses by bots, those respondents following the public access link to the were required to fill in a CAPTCHA [46]. Additionally, the respondents of the questionnaire were checked to see if they fit within the three different target subgroups (i.e. commercial parties, government authorities and local groups). If not, they were not included in the analysis. On the other hand, the identified stakeholders were given the opportunity to suggest other stakeholders during completion of the questionnaire. This technique is known as the snowball technique, first developed by Goodman [47] and then used by many other authors [48, 49]. Then, when those stakeholders were not on the “initial stakeholder list” they were added to it and the questionnaire was sent to them. Social media sharing and the snowball technique increased the number of contacted stakeholders to 190, an increase of 7.34% (13 more stakeholders).

Description of the questionnaire

Considering the novelty of the LH PHS technology, it is expected that many stakeholders are not yet familiar with LH PHS, thus the questionnaire started with information in the form of text and figures outlining the LH PHS technology. It was estimated this information would take around 3–5 min to read. Next, the questions of

Table 1 List of all the qualitative questions included in the questionnaire

Question	Question asked to
Can you name any other "moderately important" to "very important" aspects for implementation other than the ones mentioned above?	Commercial parties, Government authorities and Local groups
Which challenges would you expect during the planning and implementation phase?	Commercial parties, Government authorities
What advantages/drawbacks do you see in improving the storage capacity? [Advantages]	Commercial parties
What advantages/drawbacks do you see in improving the storage capacity? [Drawbacks]	Commercial parties
What advantages/drawbacks do you see in improving the transmission capacity? [Advantages]	Commercial parties
What advantages/drawbacks do you see in improving the transmission capacity? [Drawbacks]	Commercial parties
What alternatives do you see for the storage of renewable energy generated in the coastal regions?	Commercial parties, Government authorities and Local groups
What prospect fields of research would you like to see regarding "seawater low-head pumped hydro storage system feeding energy into the European grid"?	Commercial parties
Any other comments/questions?	Commercial parties, Government authorities and Local groups

the questionnaire followed. It was estimated that each respondent would need around 15–20 min to complete all the questions.

The questionnaire was developed for the three different stakeholder subgroups (i.e. commercial parties, government authorities and local groups). Recognizing that not all questions are relevant to every stakeholder subgroup, specific questions were directed to each subgroup while maintaining a majority of questions common to all three subgroups. A mixed-methods approach including both quantitative and qualitative questions is used. Quantitative questions allow the researchers to rank stakeholder concerns and preferences, allowing for statistical analysis and thus ranking of criteria, whereas qualitative questions can reveal unexpected feedback and allows respondents to avoid being biased by readily-available answers given by researchers as in quantitative questions. Considering the novelty of LH PHS, the researchers want to gather undisturbed/unbiased replies with the aim of not leaving out any aspect of concern or any knowledge the respondents can give and qualitative questions allow for that.

The initial questions of the questionnaire pertained to socio-demographic characteristics of the respondents. They could identify themselves with any of the three stakeholder subgroups, indicate their country of residence and indicate the respondent's position within the company or organization they represented in the questionnaire. Additionally, questions were included to analyze their degree of knowledge of similar technologies to LH PHS such as traditional high-head PHS. This could indicate if stakeholders need more information to form an opinion about the technology or if they already possess sufficient knowledge. This is because LH PHS grows out of traditional PHS, so if they are unfamiliar with traditional PHS, understanding LH PHS will be harder. In addition, the respondents can state whether or not they are currently involved in renewable energy projects and/or if they are familiar with renewable energy (RE) technologies.

Then, questions followed that aimed to gather stakeholder opinions.

Table 1 showcases the qualitative questions included in the survey. To ease reading, the quantitative questions are displayed in the results section. However, we remind the reader that all questions can be seen in the original dataset: 0.24355/dbbs.084–202301101711-0.

Within the quantitative questions, Likert scales with ranges of 1–5 and 1–7 are used to gather stakeholder opinions that can rapidly be statistically analyzed. These questions can provide a quick insight into what stakeholders prefer on average (by calculating the average between 1 and 5 or 1 and 7) and about the similarity among replies (standard deviation). Multiple choice questions allow for fast stakeholder opinion gathering in cases when ranking is not favorable, for example the "not in my backyard" (NIMBY) type question (see Fig. 5). There is no conclusive research about when to use Likert scales a range of 1–5 vs. 1–7 [50], even though Weijters et al. [51] recommended 1–5 scales for the general public and 1–7 for the educated public. For this piece of research, a scale of 1–7 was used where more detailed answers were desired, i.e. for evaluation of importance of LH PHS and for ranking multiple statements (the 1–5 scale could have also been used for the former, but the addition of the 1–7 scale gives more room to different answers and thus more probability of having statistical differentiation among the chosen statement for later ranking). The 1–5 scale was used for indicating agreement and importance as well as for ranking aspects of concern. Agreement could have been evaluated on a 1–3 scale (disagree, neutral, agree) but the 1–5 scale gives more room for indicating strong (dis)agreement, something the researchers evaluated as necessary. For ranking aspects of concern, the 1–7 scale could have been used as well, however the lesser amount of aspects to rank, allowed the simpler use of the 1–5 scale.

The distribution, presentation and recording/data collection of responses was carried out with the Limesurvey™ software. This software has some convenient features for conducting questionnaires, such as presenting the pre-defined answers of the quantitative questions in a random order to avoid order bias (primacy effects) [52]. Survey participants were able to access the survey online via a link that was sent to them (stakeholders included in the so-called "initial stakeholder list"; see Sect. Stakeholder identification) and additionally via a public link shared through social media (Sect. "Methods"). Once the data collection was finished, Limesurvey™ [53] allows data to be exported in several formats [54].

Data analysis

The analysis of the data was done using Python 3.9 (quantitative data) and MAXQDA [55] (qualitative data). Python was used to generate plots and calculate the mean, median, standard deviation (SD) and first quantile of the respondent's answers for the 1–5 and 1–7 Likert scales. In the present study the mean is used as the statistical term for ranking the responses. The median is used as a secondary way of ranking answers. For instance, if different answers rank differently in terms of mean and median, it means that the mean could be largely affected by extreme values. This can also partially be seen with the standard deviation (SD, where a larger SD implies a larger variety of responses chosen by the respondents, whereas a smaller SD indicates that all respondents' answers were similar). Finally, the 1st quartile (Q1) is used as an additional measure of answer dispersion. If the median and 1st quartile coincide, we know that at least 75% of the answers were similar (this will generally coincide with low values of SD).

The open-ended questions were analyzed using the MAXQDA software, which allows for coding of the data and then visualization and statistics of the codes. There are no universal procedures for analyzing qualitative data, even though several authors have given their recommendations on how to proceed [56–58], it is recommended to adjust existing methods to each individual research question [59]. Within the qualitative analysis, each qualitative question was analyzed individually, considering the most recurrent codes. The codes emerged from an inductive approach, meaning that the researchers first read the data without any pre-conceived codes in order to induct the codes from the given responses. This is due to the novelty of the technology and the researchers' conviction that they could learn something unexpected from the respondents. The codes emerged from existing words in the text and then they were put in common. After discussion, the codes were fixed and answers that fitted each code were identified [60]. In addition, relationships between responses to different questions, including quantitative ones, are also highlighted.

Results

The survey was eventually completed by 29 respondents. It was completed by commercial parties (16 respondents), local groups' representatives (8 respondents) and government authorities' representatives (5 respondents). The majority of the respondents reside in Germany (12 respondents), then The Netherlands (8 respondents), France (3) and Italy, Sweden, Indonesia, Norway, Austria and Mexico (each having 1 respondent). Most of the respondents occupy positions of responsibility within their company/organization such as managers, senior engineers and heads of department (22 out of 29, i.e. 76% of the respondents). This is advantageous for reliability in gathering technical expertise, aligning with the specific objectives. However, the research objective "To investigate potential redlines respecting location of LH PHS" would benefit from a larger sample of non-technical respondents.

The following answers confirmed the acquaintance of the respondents with the knowledge field of LH PHS. First, for the multiple choice question "Are you familiar with high-head pumped hydro storage technology?", 76% of the respondents (22) chose "Yes, I am aware of its use for energy storage" as an answer, 17% "Yes, I heard about it" and just 2 stakeholders from the local groups subgroup were not familiar with it, having chosen "No, but I know other large-scale storage technologies" and "No, I am not familiar with how the energy system works" as answers to the posed question. Second, two thirds of the respondents within the subgroups "commercial parties" and "government authorities" answered "Yes" to the following question: "Does the institution you represent have experience with similar projects? (for example, pumped hydro storage, any kind of hydropower, motor electronics, new grid connections…)". Keeping these respondent's characteristics in mind, the quantitative and qualitative data is analyzed in the following sections.

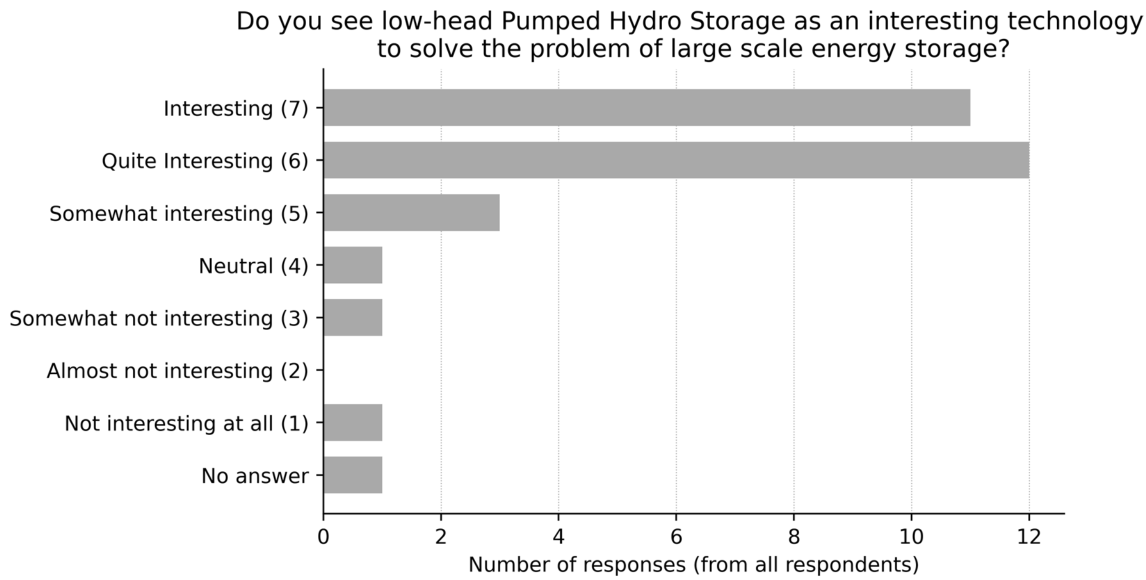

Fig. 2 All respondents' answers to the question "Do you see low-head Pumped Hydro Storage as an interesting technology to solve the problem of large scale energy storage?". The possible answers were: "7 – Interesting", "6 – Quite interesting", "5 – Somewhat interesting", "4—Neutral", "3 – Somewhat not interesting", "2—Almost not interesting", "1 – Not interesting at all" and "No answer". The x-axis indicates how many times each answer was chosen. Q1 = 6, median = 6, mean = 5.9, SD = 1.34

Quantitative data analysis

To the question "Do you see low-head Pumped Hydro Storage as an interesting technology to solve the problem of large-scale energy storage?", 76% chose either an answer of "6 – Quite interesting" or "7—Interesting" (all answers are presented in Fig. 2). Just one respondent from the local groups responded "1 – Not interesting at all". This shows that overall, respondents are very positive about the LH PHS technology, which could in turn indicate future acceptance.

Respecting implementation of LH PHS, the aspect that concerns all respondents the most is economics, then effect on the environment, bureaucracy, landscape effects, and constructability (the actual question text together with the possible ranking replies are included in the caption of Table 2; this is valid for all quantitative questions presented in this section.). Table 2 shows that the mean ranking of "Economics" is the highest (4.43), with also the lowest standard deviation (0.623), meaning that respondents gave similar grades (i.e. importance) to the "economics" factor. "Effect on the environment" ranks in second position overall. However, it would rank first according to the median. This, together with its large SD (0.914) shows that there is a large spread among responses. Grouping the responses by stakeholder type shows that commercial parties considered "Economics" to be a more influential factor, ranking "Affection to environment" as the second-most important concern. On the other hand, for government authorities and local groups "Affection to environment" is the most important factor. Government authorities ranked "Economics" as the third most important concern whereas local groups ranked it in second place. The concern about "bureaucracy" received a large spread of responses among all respondents and stakeholder subgroups. It ranks in second place for the government authorities subgroup with a mean of 4.60 (SD = 0.800), and third place for both commercial parties and local groups with means of 3.75 (SD = 1.35) and 4.00 (SD = 1.20) respectively. "Landscape affection" and "Constructability" are the least important concerns. For the commercial parties, "Landscape affection" was ranked last overall, while for both government authorities

Table 2 All respondent's answer to the question: What aspects would concern you the most when thinking about the implementation of low-head Pumped Hydro Storage? (1–5 question: 1—Not important at all, 2 – Slightly important, 3 – Moderately important, 4 – Important, 5 – Very important). Aspects are displayed from top to bottom coinciding with more and less concern respectively

Answer text	Mean	SD	Median	1st quartile
Economics	4.43	0.623	4.50	4.00
Affection to environment	4.31	0.914	5.00	4.00
Bureaucracy	3.96	1.267	4.50	3.00
Landscape affection	3.59	0.891	4.00	3.00
Constructability	3.50	0.982	3.50	3.00

Table 3 All respondent's answer to—QUESTION: According to you, which is the degree of importance of the following characteristics when choosing for a location of a low-head pumped hydro storage station? (1–5 question: 1—Not important at all, 2 – Slightly important, 3 – Moderately important, 4 – Important, 5 – Very important). Characteristics are displayed from top to bottom coinciding with more and less importance respectively

Answer text	Mean	SD	Median	1st quartile
Proximity to the existing grid	4.14	0.776	4.00	4.00
Distance from shoreline	3.76	0.816	4.00	3.00
Integration in an existing offshore wind park	3.57	1.015	4.00	3.00
Distance to shipping routes	3.04	1.239	3.00	2.00

and local groups "Constructability" was ranked last. There is therefore a clear difference between the companies and government authorities subgroups. Whereas companies are more concerned about the profitability of the project, government authorities seem much less worried about that, and more about environmental affection and bureaucratic matters. The local groups take a middle position, being mainly concerned about environmental affection and secondly about costs. This could indicate that different stakeholder subgroups may have different criteria for acceptance of the technology, according to their interests.

Respondents also had the opportunity to indicate any other aspects they would consider important for implementation of a LH PHS plant. With this, the aspects of concern they could express were not restricted to the ones presented in Table 2. Respondents once more highlighted the importance of sustainability and economics. Additionally, other relevant concerns came up; these are: renewable energy integration within the European grid, feasibility of the technology, maintenance of the plant, structural integrity, land use and public acceptance. Further analysis of these responses is done in the beginning of the following section as a part of the qualitative analysis.

The survey then asked respondents to give a first opinion about important technological or logistical characteristics respecting the implementation location of a LH PHS plant (See Table 3). Table 3 shows that half of the respondents ranked with at least a "4 – Important" the first three characteristics (median = 4.00). However, when calculating the mean, "Proximity to the existing grid" ranked as the most important concern (mean of 4.14, SD = 0.776). When analyzing the results per stakeholder subgroup, their replies lead to another relevant finding. Commercial parties and local groups, ranked "Proximity to the existing electricity grid" in 1st place. This would, in case of implementation, reduce the cost of connections and ensure lower grid losses. However, the government authorities' subgroup ranked "Proximity to the existing grid" in 2nd place and they considered "Integration in an existing offshore wind park" to be the most important concern for implementation. This indicates that government authorities have seen potential for using the LH PHS technology as a way of providing large-scale energy storage in the offshore wind projects being developed in the North Sea. "Distance from the shoreline" ranked in second place overall as well as for companies and local groups, being in 3rd place for government authorities. Finally, "Distance to shipping routes" didn't receive much attention. The general guidelines against interrupting shipping routes should be followed, but no further actions appear necessary from this analysis. The omission of choosing this answer may however also have to do with the overall composition of the stakeholder group that finished the survey, as any representatives from shipping-related companies participated in the survey.

To understand respondents concerns in a more quantitative way, they were asked to rank a series of statements on a Likert (1–7) scale from not important at all to extremely important. The result can be seen in Table 4 below.

RE integration ranks highest overall (at least 76% of the respondents rated "PHS is able to introduce more RE into the grid" as very important or extremely important), this is related to the previous question where government authorities were interested in integration of LH PHS into existing offshore wind parks. "Inundation of the surrounding coastal areas after dike breaching" ranked second. PHS and LH PHS plants consist of a single or two reservoirs from and into which volumes of water are pumped. Dams or ring dikes are required to contain these volumes, inherently posing a hazard in those cases where safe conditions are exceeded and the dike breaches or fails. In case of failure of dams, dikes or closures of water containments, such as the Upper Taum Sauk, Missouri, USA [61], Gangneung dam, South Korea [62], or even glacially-evolved lake dams [63], dam break waves are frequently observed, simulated or researched. Learnings from those cases can be applied for modelling of dike failure of a LH PHS located in the sea. Respecting LH PHS, preliminary studies such as [15, 36], showed that casualties could happen for the event of dike breach if the LH PHS plant were located in the Markermeer (a large lake in the Netherlands). However, there is no clear evidence of how a dike breach of a LH PHS situated in the North Sea will affect the adjacent coast. Therefore, research is needed to ensure safety in the event of a dike breach. Furthermore, it must be properly disseminated

Table 4 All respondents' answers to—QUESTION: Please indicate if you consider the following statements irrelevant or important. (1–7 question: 1—Not important at all, 2 – Not very important, 3 – Somewhat unimportant, 4 – Neither important nor unimportant, 5 – Somewhat important, 6—Very important, 7 – Extremely important). Statements are displayed from top to bottom coinciding with more and less importance respectively

Answer text	Mean	SD	Median	1st quartile
PHS is able to introduce more RE into the grid	6.07	0.785	6.00	6.00
Inundation of the surrounding coastal areas after dike breaching	6.00	1.363	6.00	6.00
LH PHS station interferes w/ fish migration area	5.75	1.184	6.00	5.75
Fishes could die in the pump-turbine operation	5.72	1.171	6.00	5.00
Negative affection bottom ecosystem	5.68	1.283	6.00	5.00
Large initial investment costs	5.56	1.133	6.00	5.00
installation depth 10-40 m	5.52	0.895	6.00	5.00
landscape affection of the LH PHS structure	5.14	1.358	5.00	5.00
mountain valleys won't be flooded nor river flows disturbed	5.14	1.224	5.00	5.00
innovative aspect of LH PHS	5.11	1.113	5.00	4.00
Job creation	4.97	1.377	5.00	4.00
Possible negative affection to the tourism industry	4.48	1.316	5.00	3.00
LH PHS does not use freshwater	4.14	1.795	4.00	3.00
Possible positive affection to the tourism industry	4.10	1.494	4.00	3.00

to stakeholders as failure to ensure that coastal safety is expected to significantly decrease public acceptance. Fish migration and fish friendliness are the aspects ranked next in importance. Waters and Aggidis [64] found a 3.6% mortality rate for adult salmon and sea trout smolts using computer modelling of fish migration and movement patterns for the Swansea Bay Lagoon project. This could be considered not good enough by stakeholders, especially for local groups, which ranked "Fishes could die in the pump-turbine operation" as the second-most important statement with an average ranking of 6.00 (SD = 1.32). Fish screens are an attractive technology for reducing and attempting to eliminate fish mortality [64]. Based on the respondent's interest in fish friendliness, it is recommended to study aspects including what is a tolerable fish mortality rate, differentiating what species shouldn't be affected at all, etc. Inclusion of local coastal communities as well as individuals involved in the fishing industry and fish conservation matters is recommended. The next most important statement was "Negative effects on the bottom ecosystem", which is related with the "effect on the environment" concern from Table 2. Again, respondents show large interest in being as harmless to the environment as possible. This is in line with the development of a LH PHS project that aims to reduce CO_2 emissions. Next in the list of ranked statements from Table 4, we have "Large initial investment costs". This is seen to be important (again a relation with Table 2, where "Economics" was the most important concern) for respondents. However, in this case Table 4 shows that respondents have rated environmental issues higher than costs of construction, which could mean that stakeholders would assume high construction costs as long as the structure is profitable in the long term. In any case, this could change when actual costs of LH PHS plants are determined. Finally, statements related with construction were ranked next followed by least important statements such as effects on tourism and the innovative aspect of the technology, comparable to the results of Table 2.

To comprehend how commercial parties perceive the impact of a LH PHS plant project on their operations, the question "Based on the current information, the company I represent will be negatively affected by a project of a low-head pumped hydro station" was asked (see Fig. 3).

These companies feel that they will not be negatively affected by a LH PHS project. Additionally, they feel that they have the resources/knowledge necessary to be involved in a LH PHS project (see Fig. 4). This is one of the advantages of this kind of technology, that most of its parts have been already developed in dike construction, pump station construction or tidal power plants. This creates extra business opportunities for manufacturers, designers, investors and project developers currently working in the previously mentioned industries. Furthermore, these results may increase this subgroup's future acceptance of LH PHS.

In connection with the possible answer "distance from the shoreline" to the question's response outlined in Table 3, an additional question was then directed to the local groups and the government authorities subgroups. In this question they were asked about the so-called attitude "Not In My Back Yard (NIMBY)" [65]. The question

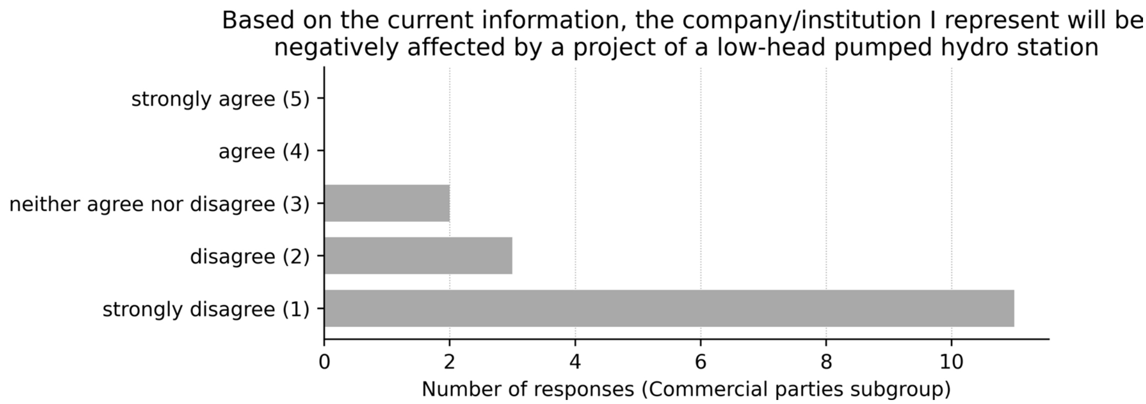

Fig. 3 Commercial parties subgroup answers to the question "Based on the current information, the company/institution I represent will be negatively affected by a project of a low-head pumped hydro station". The possible answers were: "5—strongly agree", "4—agree", "3—neither agree nor disagree", "2—disagree", "1—strongly disagree", "No answer". This question was only presented only to the commercial parties' stakeholder subgroup. Q1 = 2, median = 1, mean = 1.44, SD = 0.704

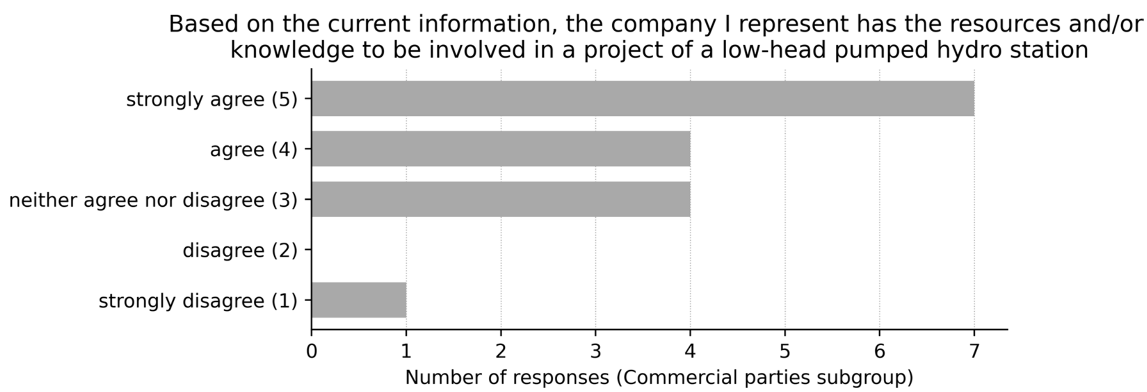

Fig. 4 Commercial parties subgroup answers to the question "Based on the current information, the company/institution I represent has the resources and/or knowledge to be involved in a project of a low-head pumped hydro station". The possible answers were: "5—strongly agree", "4—agree", "3—neither agree nor disagree", "2—disagree", "1—strongly disagree", "No answer". This question was only presented only to the commercial parties' stakeholder subgroup. Q1 = 2, median = 1, mean = 4.0, SD = 1.12

is presented in Fig. 5. Two (15,4%) respondents did not know what to answer and one (7.7%) respondent decided not to answer the question. These answers are within the local groups subgroup. All respondents within the government authorities' subgroup were positive about having a LH PHS plant installed close to the coast. Therefore, so far, and in contrast with previous infrastructure projects that have seen implementation [66–68] there are no negative answers regarding the location of a LH PHS plant close to the shore. In any case, it is important to mention that recent literature considers the NIMBY issue to be very simplistic when considering acceptance [27].

Qualitative data analysis

As explained in the previous section, the first question analyzed in the present section is the open answer from Table 2: "What aspects would concern you the most when thinking about the implementation of low-head Pumped Hydro Storage?" Stakeholders had the opportunity to "name any other "moderately important" to "very important" aspects for implementation", thus providing additional concern beyond those listed in Table 2. The coded questions showed that stakeholders were mostly interested in sustainability aspects (21% of the answers were coded as "sustainability"), already included in the original quantitative question as "Affection to environment". Almost all answers categorized as "sustainability" were very general, not adding unexpected concerns. Only one stakeholder answered "Wadden Sea National Park stands against implementation, Natura 2000 as well", drawing a red-line with respect to where to locate LH PHS. "Natura 2000 is a network of core breeding and resting sites for rare and threatened species" [69], some of which are located within the North Sea (area of study

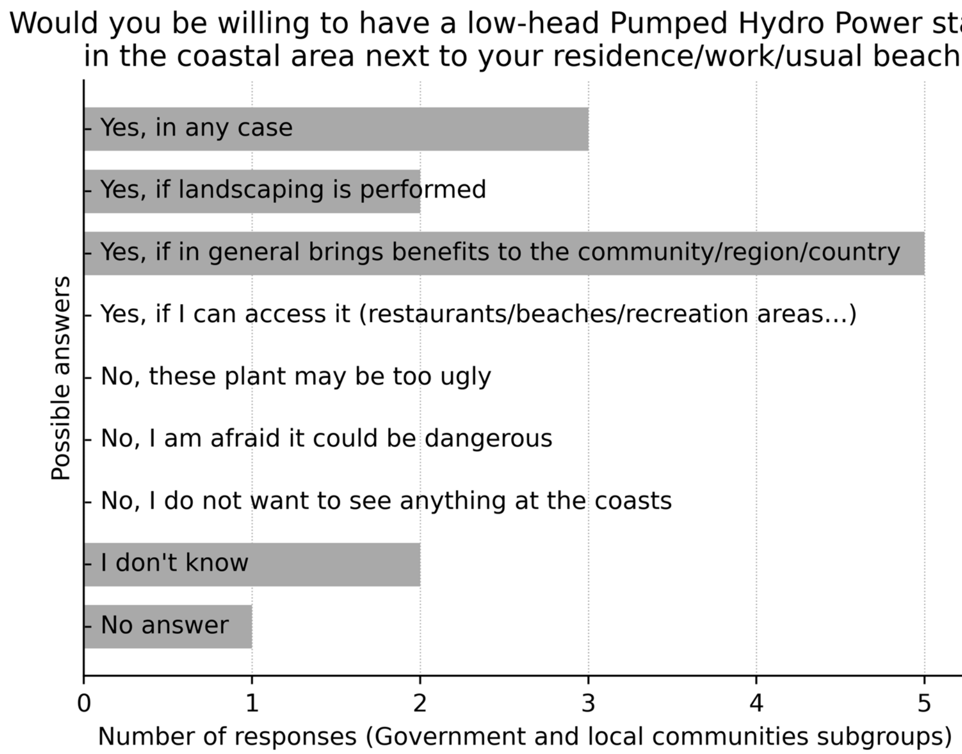

Fig. 5 Government authorities and local groups stakeholder subgroups' answer to the question: "Would you be willing to have a low-head Pumped Hydro Power station in the coastal area next to your residence/work/usual beach?". Each answer option provided to the stakeholders is displayed in y-axis of the figure, with the number of times respondents selected each option shown on the x-axis. The horizontal grey bar represents the frequency of each answer choice selected by the respondents

of the present analysis). Even though the competence of permitting construction in a Natura 2000 area does not belong to this stakeholder, it is clear that strong opposition will arise if construction is planned within it. If construction in a Natura 2000 area were to occur, adequate environmental plans must be presented that show that construction of a LH PHS is an improvement in the general sustainability of an area when compared to the original state of the protected area [15]. Much can be learned from existing knowledge on the implementation of offshore wind farms where extensive Environmental Impact Assessment (EIA) [70] is required [71, 72]. As EIAs are generally time consuming and expensive, most likely the assessments are even more demanding in Natura 2000 areas and thus may be avoided after all due to the extra bureaucratic work involved. The second-most mentioned category was "technology" (16%), but answers were too general ("technology" and "maintainability technology") to draw any conclusion from them. Most of the responses were either already in the original wording of the quantitative question (answers: "constructability", "affection to environment", "economics", "landscape affection" and "bureaucracy"), or very general ("Nature conservation", "Plant/unit governing stability" and "Government financing of the project" to name a few) to provide any significant insights. However, one response (from the companies subgroup) put the focus on a singular aspect of the constructability: "Water level Lake and pore pressure soil and groundwater. If lake is at high level or at low level makes much difference on soil water mechanics". When analyzing the different kinds of dike ring structures for the LH PHS reservoir, the pore pressures within the surrounding soil should be considered. A preliminary analysis was done by van Adrichem [73], concluding that it did not have significant effects on dike stability. However, considering that the cited work is a student's master thesis, further research is recommended to confirm the findings.

Based on the respondent's familiarity with similar technologies to LH PHS and the fact that commercial parties believe their expertise could be used to develop a LH PHS project, the following question gains relevance: "Which challenges would you expect during the planning and implementation phase?". Most of the responses focus on bureaucratic or political procedures (23%), such as "Preparation of the implementation plan with regard to the legal requirements for approval.", "Acquire the appropriate permits and licenses considering the unavailability of (environmental impact) data" or "Will to implement pumped storage of different systems to be able to balance the volatility of increasing wind and solar energy". Then again, this time ranking in second place, the economics aspect was highlighted by the stakeholders (19%). In relation with this, in the previous question we saw that a stakeholder stated "Government financing of the project". Governments can make a large impact on the development of energy projects, as was the case for offshore wind power in the United Kingdom [74] and China [75]. Recently, this technology has been shown to be competitive with other energy generation technologies even without subsidies in the markets of the Netherlands and Germany [76]. These results suggest that if the political will exists to implement LH PHS, the economic aspect could be eased, as was the case for offshore wind. The third most important issue is related to stakeholder acceptance (15%): "Consequences of environmental legislation and stakeholder acceptance". Huijts et al. [77] discuss multiple factors that increase stakeholder acceptance (knowledge, costs, risk and benefits, moral evaluations, hedonic goals, experience, trust, and fairness of the procedure, amongst others). The current analysis of stakeholder opinions could be considered an effort to increase stakeholder acceptance, considering the survey increases the knowledge of the stakeholders about LH PHS. Additionally, the survey is a tool for including stakeholder feedback in the LH PHS design from the stage of early technological development.

Furthermore, the questionnaire also included four open-ended questions related to stakeholder views on advantages and disadvantages of increasing the energy storage capacity or increasing the energy transmission capacity in the European grid. The goal was to identify particular differences in each of the alternatives used for improving wind energy penetration within the grid [78–82]. The stakeholders coincided that both alternatives' most important advantage is the increase in the renewable energy penetration within the grid. This advantage was clearer for energy storage (11 coded answers, 79%) than for improvement in transmission capacity (8 coded answers, 67%). The advantages for both methods stated by the respondents were generally very similar, mostly related with increase of renewable energy penetration into the grid. However, the disadvantages noted by the respondents showed some marked differences. Respecting the improvement of the storage capacity, the main disadvantage for respondents is the required use of land: "large scale storage often comes with giant projects" and "10–20 m pumping high is quite low, therefore a huge basin is needed (extremely costly)" were answers that show concerns with the overall dimensions of the civil structure. Additionally, electricity production and construction costs of the project could again be a disadvantage, according to the respondents: "Energy vs investing ratio could be low.". For the increase of transmission capacity methods, mainly "costs" were identified as the major disadvantage. Therefore, no significant new insights have been gained from this question.

To help identify competing technologies that might divert investment from LH PHS technology, the question "What alternatives do you see for the storage of renewable energy generated in the coastal regions?" was presented to the respondents. "Batteries" (24%) and "hydrogen" (20%) were the most mentioned technologies. Furthermore, one respondent detailed the storage scales for batteries and hydrogen: "short-term storage with battery systems" or "seasonal storage could be done via hydrogen". Hydrogen could compete with large scale seasonal storage, however the conversion from electricity into hydrogen and then again into electricity has a low round-trip efficiency (around 54% [83]) compared to conventional PHS systems (around 80% [13]) which is similar to the roundtrip efficiency the current development team for LH PHS aims to achieve (around 80%). Nevertheless, LH PHS could still be used together with hydrogen. Hydrogen storage could be relevant when the hydrogen can be used directly as a fuel, but LH PHS may have an advantage for electricity storage because of its high efficiency. Other interesting technologies were also mentioned such as "Buoyancy Energy Storage Technology", which is a novel technology that uses the buoyant force of a submerged balloon to generate electricity. The balloon is pushed to the lower depths of the sea when there is available electricity and then released to generate electricity. Hunt et al. [84] states that this kind of technology is interesting for weekly storage, putting it between the batteries and large-scale storage such as PHS. Besides, this technology needs great water depths to be cost effective (3000 m – 6000 m) so its location is constrained to deep seas. This does not coincide with the locations of bottom-fixed offshore wind installed to date, so does not allow for energy storage at the locations of current offshore wind hubs, something LH PHS is capable of due to its installation depth range (5–30 m) [15]; however, buoyancy energy storage technology might become an option for offshore wind installations using floating foundations in deeper waters [85, 86]. According to both the respondents and literature, LH PHS could be located close to offshore wind farms. Considering its ability to store electrical energy at large scale (at timescales of hours to weeks), LH PHS has a unique market space. Additionally, it can be integrated into a system with other storage methods such as the above-mentioned options.

An additional specific objective of this work was to find new research topics, derived from the stakeholder answers. This was allowed by the question 'What prospect fields of research would you like to see regarding "seawater low-head pumped hydro storage system feeding energy into the European grid"?'. Several relevant and novel research topics where suggested, mainly in line with the rest of the stakeholder concerns in the fields of constructability, economics and environmental impact. Many of the answers are very general: "Environmental impact and fish mortality", "hazard to people and property", "Social acceptability", "Marine works strategies to reduce costs", "Pump technology or pump as turbine", "turbine designs", "Best possible integration while incorporating the least possible impact on the ecosystem.". As these are very general propositions, ongoing research already fits into these proposed areas. Nevertheless, some respondents were more specific and replied: "Elaboration of a catalog of suitable sites", "The effects of fluctuating mass of water on the surrounding area.", "Soil water mechanics especially with low level lakes.", "the joint operation with and impact on the efficiency of wind parks and solar parks" and "Effect of such a system on the electricity prices/profitability of such a system". To the knowledge of the author collective, the four last topics are not yet being studied elsewhere. Some of the potential future research suggestions indicated by the responses refer to the design of the system. Stakeholders apparently want to see, and remain very curious about, images with approximate dimensions, expected costs, generation capacity, etc. These topics remain subjects of ongoing research and thus, research results are not yet robust enough to inform stakeholders.

To finish the questionnaire, the last open-ended question was "Any other comments/questions?". However, not many respondents (4 out of 29, 14%) gave an answer, and those obtained were not relevant to the goals of the analysis. This could indicate that the survey sufficiently provided the opportunity for stakeholders to express their thoughts and opinions.

Discussion

This section includes reflections on how the questionnaire, respondents and results may have influenced the findings presented in this piece of research. First of all, despite the researchers' efforts to describe the LH PHS technology in the beginning of the questionnaire, and due to the novelty of the technology, it is possible that stakeholders did not have a clear idea of how LH PHS works, as they do for instance with conventional PHS. This could lead to less specific feedback to the open-ended questions. In fact, many of the replies were too general (i.e. "technology", "Social acceptability", "turbine designs", etc.) so no significant information could be obtained from such replies. From our analysis, we could see a relationship between less interest and limited knowledge of PHS. This is in line with what Itaoka et al. [87] found. They found that, in general, public acceptability of carbon capture and storage (CCS) increased with greater knowledge about the CCS technology. Azman et al. [88] found a similar positive relationship between knowledge and acceptance in his study. However, other authors [89, 90] argue that increasing knowledge does not necessarily increase acceptance so the first sentence has to be considered carefully.

Another reason for the general (and short) open-ended replies could be an excessive questionnaire length. However, Porter [91] and Kost and Correa da Rosa [92] showed that survey length is not a critical aspect for causing so-called survey fatigue. Factors such as multiple contacts (with tentative respondents), incentives and survey salience (interest of stakeholders in LH PHS) are more relevant. To investigate this, future surveys could be shorter in length.

One limitation of this study is the fact that it includes feedback from 29 respondents. As stated at the beginning of Chapter 3, 75% of the respondents occupy positions of importance within their organizations, which serves to gather reliable technical feedback. However, it is true that the quantitative data, specially that from questions which are asked to specific stakeholder groups, may have little data to perform a reliable statistical analysis. Therefore, these should be considered carefully.

Most of the respondents reside in Germany. This country manages a large part of the North Sea's territory and therefore their answers are significant for this research. However, the study may benefit from a larger sample from other North Sea countries. Furthermore, two respondents are from outside of Europe (Indonesia and Mexico) and their answers were considered relevant for this study. The reasoning behind this is twofold. First, it is because they are from the commercial parties stakeholder subgroup. Therefore, the in-depth location-based question (see Fig. 5) was not asked to them. Second, the researchers recognize the value of gathering technical feedback independently from their geographic region, considering more important whether or not they have knowledge about the PHS technology, as was the case for the non-European respondents. Additionally, the Mexican respondent had previous experience working with hydropower projects, which could make their technical answers more relevant compared to respondents that did not know about PHS nor had previous experience with hydropower even though their geographic region was within European territory.

One important bias of the gathered responses could arise from the fact that the commercial parties stakeholder subgroup accounted for more than 50% of the total respondents. As demonstrated in the results of various quantitative questions in the previous section, the ranking of the answers differs for each stakeholder subgroup, suggesting that a higher number of responses from the local groups and government authorities stakeholder subgroups could generate slightly different results. The influence on results is only expected to be minor because as already shown in the previous section, it is not the case that the first ranked answer for one of the stakeholder subgroups is the least important one for another subgroup. In any case, given the early stage of technology development, the feedback from technical respondents is valuable for the research questions of this research.

As expected by the researchers, the qualitative questions showed unexpected feedback to the question "Which challenges would you expect during the planning and implementation phase?". Mainly technical replies were anticipated, but the respondents' main expected challenge for implementation of LH PHS was about preparing licenses and the follow-up permitting processes. Table 2 showed that when considered as a concern, the bureaucratic aspects rank lower than economics or environmental affection. However, in an open question about challenges, the respondents decided to highlight the bureaucratic processes. This difference may be due to the absence of specific questions addressing these considerations. Studying the development of legal licenses or particularities about the permitting process was not considered in the research questions, however the mentioning of this by respondents opens up additional research topics about the bureaucratic processes involved in permitting and approving construction and operation of a LH PHS. As none of the stakeholders provided specific feedback about what parts of the legislation could be most cumbersome to deal with, future research is recommended to discover these. Previous literature shows that Helm (2014) [93] identified three issues for the European energy market: 1) different energy prices for each European Union (EU) Member State (MS), 2) 27 different national energy policies (a different one for each MS) and 3) lack of energy interconnections. He concluded that "Europe's energy and climate policies are going nowhere" since they drive up prices, drive down competitiveness, and do not have a substantial impact on mitigating climate change. Tol [94] also found that the EU policy leads to a high cost/benefit ratio. These results also coincide with those from [95]. Regarding energy policy, Polzin et al. [96] found that feed-in-tariffs (FIT), auctions and renewable portfolio standards are the most effective policy instruments for mobilizing funding of renewable energies. We recommend further investigation of available energy policies for LH PHS and put a focus on the role that FIT and auctions could have in LH PHS development.

The results obtained in this study apply to the North Sea. In general, literature states that different solutions are needed for different geographic, historical, political, and social structures across different countries and regions [97]. Particularly, the technical aspects to be considered (water depth, soil conditions or environmental forces, to name a few) in a sea other than the North Sea are different and thus feedback from technical experts regarding technical issues may vary along with their technical concerns for acceptance. Furthermore, trust in those responsible for a project varies per country. Liu et al. [98] found that for similar renewable energy projects in both China and the Netherlands, trust in agents in charge of projects (being different for each country) correlated with high acceptance. Lastly, Huijts et al. [77] found that people who have more experience with solar and wind renewable energy production facilities show higher acceptance than those who do not. This suggests that countries with less renewables deployment that those surrounding the North Sea, will show less acceptance towards LH PHS. Therefore, the stakeholder opinions and recommendations of this study cannot be directly applied to locations other than the North Sea.

Finally, we would like to state that the results obtained may vary as more information about LH PHS is discovered and shared. Furthermore, we expect public opposition to be stronger in the implementation phase of the project in comparison with the early research stages, where we currently are. Therefore, stakeholder opinions should be gathered continuously over time.

Conclusions

The present study represents a starting point for assessing stakeholder opinions with respect to LH PHS. We identified the stakeholders' views of the main challenges and risks facing implementation of LH PHS. The stakeholders did not identify any red lines concerning proposed locations of a LH PHS plant. Additionally, companies reported to have the knowledge and resources for developing a LH PHS plant in the North Sea. Finally, possible future research topics of interests for stakeholders were also identified.

Based on the survey responses, economic and technological feasibility as well as environmental impact are the biggest challenges for implementation. Due to the innovative character of the LH PHS technology, its economic and technological feasibility, which are still a large uncertainty in this new field, should be further investigated [12, 15]. A potential risk that concerns respondents in respect to technological feasibility is the flood risk and structural damage that a dike breach could cause along neighboring coastlines. Special attention should be placed on this safety aspect when designing a LH PHS plant. The environmental impact concern grows from the large structure footprint necessary for increasing grid-storage capacity and the risk of causing a negative effect on its surroundings. From the results presented here, we expect that locating a LH PHS plant within a nature conservation area will lead to great public opposition and therefore, from a public acceptance point of view, these areas must be avoided. We found no other stakeholder requirements with respect to the location of these plants, suggesting that the NIMBY phenomenon is not a major issue at this early stage.

A share of 69% of the respondents from the commercial parties subgroup considered that their institution has the resources and/or knowledge to be involved in a LH PHS project. This presents opportunities for actual construction of the LH PHS with current available design, manufacturing and construction methods. Companies do not have to invest a large amount of resources into generating new methods since LH PHS is a technology that grows out of existing technologies such as tidal power and pumped hydro energy storage [15]. This could indicate continued future acceptance of the technology from the commercial parties stakeholder subgroup.

The suggested research topics indicated by the stakeholders are based on the stakeholder concerns (economic and technological feasibility, environmental impact and public acceptance). Starting with the economics and constructability of a LH PHS station, research into pump-turbine technology was specifically highlighted by the respondents. Equally, they indicated the importance of water dynamics around the reservoir of a LH PHS plant, particularly the constantly varying inner reservoir water level. In this respect, research about water pressures inside the dike is also of interest to respondents. Additionally, respondents want to be presented conceptual designs of a LH PHS storage plant; this will be an important step in involving stakeholders as visuals will be a more powerful tool to convey messages to technical or general stakeholders than written descriptions. Environmental impact analyses were also of interest, but respondents did not specify any specific research topics in this respect. Energy policy and public acceptance were two other research fields suggested for pursuit in future research activities. Acceptance must be monitored as the LH PHS technology grows, keeping stakeholders updated about the latest research findings.

We conclude that LH PHS presents itself as an interesting option for increasing the energy storage capacity of the European grid, which will enhance future project acceptance. In any case, stakeholder opinions must be monitored as the LH PHS technology grows, and stakeholders must be updated about the latest research findings.

Abbreviations

LH PHS	Low-head pumped hydro storage
PHS	Pumped hydro storage
RE	Renewable energy

Acknowledgements
This paper was funded by the European Union Horizon 2020 project ALPHEUS (Augmenting grid stability through Low-head Pumped Hydro Energy Utilization & Storage) project ID 883553.

Author contributions
RA conceptualized the research, designed the questionnaire, analyzed and interpreted the data and wrote the manuscript. DS conceptualized the research, wrote the manuscript and supervised the research, JB conceptualized the research, wrote the manuscript and supervised the research, MO conceptualized the research, designed the questionnaire, interpreted the data and wrote the manuscript, NG conceptualized the research, wrote the manuscript and supervised the research.

Funding
Open Access funding enabled and organized by Projekt DEAL. This paper was funded by the European Union Horizon 2020 project ALPHEUS (Augmenting grid stability through Low-head Pumped Hydro Energy Utilization & Storage) project ID 883553.

Availability of data and materials
Ansorena Ruiz, Ruben: Stakeholder views about the low-head pumped hydro storage technology. Online under: https://leopard.tu-braunschweig.de/receive/dbbs_mods_00071841. 0.24355/dbbs.084-202301101711-0.

Declarations

Ethics approval and consent to participate
The authors obtained written consent from all participants, in accordance with the "Consent form" included in the document "StakeholderQuestionnaire_LHPHS.pdf", which can be found in the shared data complementing this manuscript.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Author details
[1]Division of Hydromechanics, Coastal and Ocean Engineering, Leichtweiß-Institute for Hydraulic Engineering and Water Resources, Technische Universität Braunschweig, Beethovenstraße. 51A, 38106 Brunswick, Germany. [2]Department of Hydraulic Engineering, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Stevinweg 1, 2628 CN Delft, The Netherlands. [3]Department of Civil and Environmental Engineering, University of Michigan, 2350 Hayward, Ann Arbor, MI 48109-2125, USA. [4]Division of Industrial/Organizational and Social Psychology, Institute of Psychology, Technische Universität Braunschweig, Spielmannstraße 19, 38106 Brunswick, Germany. [5]Coastal Research Center, Joint Research Facility of Leibniz University Hannover and Technische Universität Hannover, Merkurstraße 11, 30419 Hannover, Germany.

Received: 5 October 2023 Accepted: 3 June 2024
Published online: 10 June 2024

References

1. European Comission (2021) A European Green Deal. In: Eur. Comm. - Eur. Comm. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en. Accessed 23 Nov 2022
2. Glenk G, Meier R, Reichelstein S (2021) Cost dynamics of clean energy technologies. Schmalenbach J Bus Res 73:179–206. https://doi.org/10.1007/s41471-021-00114-8
3. Eurostat (2018) Shares of energy from renewable sources
4. Spiecker S, Weber C (2014) The future of the European electricity system and the impact of fluctuating renewable energy—a scenario analysis. Energy Policy 65:185–197. https://doi.org/10.1016/j.enpol.2013.10.032
5. Walker G (2014) The dynamics of energy demand: Change, rhythm and synchronicity. Energy Res Soc Sci 1:49–55. https://doi.org/10.1016/j.erss.2014.03.012
6. Kroposki B, Johnson B, Zhang Y et al (2017) Achieving a 100% renewable grid: operating electric power systems with extremely high levels of variable renewable energy. IEEE Power Energy Mag 15:61–73. https://doi.org/10.1109/MPE.2016.2637122
7. Ma J, Silva V, Belhomme R, et al (2013) Evaluating and planning flexibility in sustainable power systems. In: 2013 IEEE Power Energy Soc. Gen. Meet. IEEE, Vancouver, BC, pp 1–11
8. Sarkar MNI, Meegahapola LG, Datta M (2018) Reactive power management in renewable rich power grids: a review of grid-codes, renewable generators, support devices, control strategies and optimization algorithms. IEEE Access 6:41458–41489. https://doi.org/10.1109/ACCESS.2018.2838563
9. Mira-Gebauer N, Rahmann C, Alvarez-Malebran R, Vittal V (2023) Review of wide-area controllers for supporting power system stability. IEEE Access 11:8073–8095. https://doi.org/10.1109/ACCESS.2023.3237576
10. Johnson SC, Papageorgiou DJ, Mallapragada DS et al (2019) Evaluating rotational inertia as a component of grid reliability with high penetrations of variable renewable energy. Energy 180:258–271. https://doi.org/10.1016/j.energy.2019.04.216
11. Johnson SC, Rhodes JD, Webber ME (2020) Understanding the impact of non-synchronous wind and solar generation on grid stability and identifying mitigation pathways. Appl Energ 262:114492. https://doi.org/10.1016/j.apenergy.2020.114492
12. Hoffstaedt JP, Truijen DPK, Fahlbeck J et al (2022) Low-head pumped hydro storage: a review of applicable technologies for design, grid integration, control and modelling. Renew Sust Energ Rev 158:112119. https://doi.org/10.1016/j.rser.2022.112119
13. Rehman S, Al-Hadhrami LM, Alam MdM (2015) Pumped hydro energy storage system: a technological review. Renew Sust Energ Rev 44:586–598. https://doi.org/10.1016/j.rser.2014.12.040
14. Rogner M, Troja N (2018) The world's water battery: Pumped hydropower storage and the clean energy transition. International Hydropower Association
15. Ansorena Ruiz R, de Vilder LH, Prasasti EB et al (2022) Low-head pumped hydro storage: A review on civil structure designs, legal and environmental aspects to make its realization feasible in seawater. Renew Sust Energ Rev 160:112281. https://doi.org/10.1016/j.rser.2022.112281
16. Pickard WF (2011) The History, Present State, and Future Prospects of Underground Pumped Hydro for Massive Energy Storage. Proc IEEE 100:473–483. https://doi.org/10.1109/JPROC.2011.2126030
17. Lavooij H, Berke L (2019) UPDATE 2019: DELTA21
18. Dyer R (2017) Cultural sense-making integration into risk mitigation strategies towards megaproject success. Int J Proj Manag 35:1338–1349. https://doi.org/10.1016/j.ijproman.2016.11.005
19. Lawer ET (2019) Examining stakeholder participation and conflicts associated with large scale infrastructure projects: the case of Tema port expansion project, Ghana. Marit Policy Manag 46:735–756. https://doi.org/10.1080/03088839.2019.1627013
20. Schönauer A-L, Glanz S (2022) Hydrogen in future energy systems: social acceptance of the technology and its large-scale infrastructure. Int J Hydrogen Energ 47:12251–12263. https://doi.org/10.1016/j.ijhydene.2021.05.160
21. Lienhoop N (2018) Acceptance of wind energy and the role of financial and procedural participation: an investigation with focus groups and choice experiments. Energy Policy 118:97–105. https://doi.org/10.1016/j.enpol.2018.03.063
22. Pahle M (2010) Germany's dash for coal: exploring drivers and factors. Energy Policy 38:3431–3442. https://doi.org/10.1016/j.enpol.2010.02.017
23. Martinez N (2020) Resisting renewables: the energy epistemics of social opposition in Mexico. Energy Res Soc Sci 70:101632. https://doi.org/10.1016/j.erss.2020.101632
24. Velasco-Herrejon P, Bauwens T (2020) Energy justice from the bottom up: a capability approach to community acceptance of wind energy in Mexico. Energy Res Soc Sci 70:101711. https://doi.org/10.1016/j.erss.2020.101711
25. Upham P, Johansen K (2020) A cognitive mess: mixed feelings about wind farms on the Danish coast and the emotions of energy infrastructure opposition. Energy Res Soc Sci 66:101489. https://doi.org/10.1016/j.erss.2020.101489
26. Jobert A, Laborgne P, Mimler S (2007) Local acceptance of wind energy: factors of success identified in French and German case studies. Energy Policy 35:2751–2760. https://doi.org/10.1016/j.enpol.2006.12.005
27. Heras-Saizarbitoria I, Zamanillo I, Laskurain I (2013) Social acceptance of ocean wave energy: a case study of an OWC shoreline plant. Renew Sust Energ Rev 27:515–524. https://doi.org/10.1016/j.rser.2013.07.032
28. Lehrer U, Laidley J (2008) Old mega-projects newly packaged? Waterfront redevelopment in Toronto. Int J Urban Regional 32:786–803. https://doi.org/10.1111/j.1468-2427.2008.00830.x
29. Novy J, Peters D (2012) Railway station mega-projects as public controversies: the case of Stuttgart 21. Built Environ 38:128–145. https://doi.org/10.2148/benv.38.1.128
30. Devine-Wright P, Wiersma B (2020) Understanding community acceptance of a potential offshore wind energy project in different locations: an island-based analysis of 'place-technology fit.' Energy Policy 137:111086. https://doi.org/10.1016/j.enpol.2019.111086
31. Freeman RE (2010) Strategic management: a stakeholder approach. Cambridge University Press
32. Bryson JM (1988) A strategic planning process for public and non-profit organizations. Long Range Plann 21:73–81. https://doi.org/10.1016/0024-6301(88)90061-1
33. Eden C, Ackermann F (1998) Making strategy: the journey of strategic management. SAGE Publications Inc, Thousand Oaks
34. Laplume AO, Sonpar K, Litz RA (2008) Stakeholder theory: reviewing a theory that moves us. J Manag 34:1152–1189. https://doi.org/10.1177/0149206308324322
35. Starik M (1995) Should trees have managerial standing? Toward stakeholder status for non-human nature. J Bus Ethics 14:207–217. https://doi.org/10.1007/BF00881435
36. Rijkswaterstaat (RWS), Hollandsche Beton Groep NV, Ballast Nedam Groep NV, Raadg. Ing. Bur. Lievense (1986) Pomp accumulatie centrale Brouwersdam en IJsselmeer (Hoofdrapportage fase 2). Rijkswaterstaat
37. Nghiem A, Pineda I (2017) Wind energy in Europe, Scenarios for 2030. Wind Europe
38. Clarke T, Clegg S (2000) Changing paradigms: The transformation of management knowledge for the 21st century. HarperCollins Business
39. Clarkson MBE (1995) A stakeholder framework for analyzing and evaluating corporate social performance. Acad Manage Rev 20:92. https://doi.org/10.2307/258888
40. Pacheco C, Garcia I (2012) A systematic literature review of stakeholder identification methods in requirements elicitation. J Syst Software 85:2171–2181. https://doi.org/10.1016/j.jss.2012.04.075
41. Sharp H, Finkelstein A, Galal G (1999) Stakeholder identification in the requirements engineering process. In: Proceedings. Tenth International Workshop on Database and Expert Systems Applications. DEXA 99. IEEE, Florence, Italy, pp 387–391
42. Reed MS, Graves A, Dandy N et al (2009) Who's in and why? A typology of stakeholder analysis methods for natural resource management. J Environ Manage 90:1933–1949. https://doi.org/10.1016/j.jenvman.2009.01.001
43. Daume S, Albert M, von Gadow K (2014) Forest monitoring and social media—complementary data sources for ecosystem surveillance? Forest Ecol Manag 316:9–20. https://doi.org/10.1016/j.foreco.2013.09.004
44. Sedereviciute K, Valentini C (2011) Towards a more holistic stakeholder analysis approach. mapping known and undiscovered stakeholders from social media. Int J Strateg Commun 5:221–239. https://doi.org/10.1080/1553118X.2011.592170

45. Sinclair M, McCullough JEM, Elliott D et al (2021) Using social media as a research tool for a bespoke web-based platform for stakeholders of children with congenital anomalies: development study. JMIR Pediatr Parent 4:e18483. https://doi.org/10.2196/18483
46. von Ahn L, Blum M, Hopper NJ, Langford J (2003) CAPTCHA: using hard ai problems for security. In: Biham E (ed) Advances in cryptology—EUROCRYPT 2003. Springer, Berlin Heidelberg, Berlin, Heidelberg, pp 294–311
47. Goodman LA (1961) Snowball sampling. Ann Math Stat 32:148–170
48. Biernacki P, Waldorf D (1981) Snowball sampling: problems and techniques of chain referral sampling. Sociol Method Res 10:141–163. https://doi.org/10.1177/004912418101000205
49. Johnson TP (2014) Snowball sampling: introduction. In: Wiley statsref: statistics reference online. John Wiley & Sons, Ltd
50. Kusmaryono I, Wijayanti D, Maharani HR (2022) Number of response options, reliability, validity, and potential bias in the use of the likert scale education and social science research: a literature review. Int J Educ Methodol 8:625–637. https://doi.org/10.12973/ijem.8.4.625
51. Weijters B, Cabooter E, Schillewaert N (2010) The effect of rating scale format on response styles: the number of response categories and response category labels. Int J Res Mark 27:236–247. https://doi.org/10.1016/j.ijresmar.2010.02.004
52. Bowling A (2005) Mode of questionnaire administration can have serious effects on data quality. J Public Health 27:281–291. https://doi.org/10.1093/pubmed/fdi031
53. Limesurvey GmbH LimeSurvey: An Open Source survey tool
54. LimeSurvey Manual. https://manual.limesurvey.org/LimeSurvey_Manual. Accessed 24 Nov 2022
55. VERBI Software (2021) MAXQDA 2022
56. Corcoran JA, Stewart M (1998) Stories of stuttering: a qualitative analysis of interview narratives. J Fluency Disord 23:247–264. https://doi.org/10.1016/S0094-730X(98)00020-5
57. Libarkin JC, Kurdziel JP (2002) Research methodologies in science education: qualitative data. J Geosci Educ 50:195–200. https://doi.org/10.1080/10899995.2002.12028052
58. O'Connor H, Gibson N (2003) A step-by-step guide to qualitative data analysis. Pimatisiwin J Aborig Indig Community Health 1:63–90
59. Patton MQ (1999) Enhancing the quality and credibility of qualitative analysis. Health Serv Res 34:1189–1208
60. Hsieh H-F, Shannon SE (2005) Three approaches to qualitative content analysis. Qual Health Res 15:1277–1288. https://doi.org/10.1177/1049732305276687
61. Rogers JD, Watkins CM, Chung J-W (2010) The 2005 upper taum sauk dam failure: a case history. Environ Eng Geosci 16:257–289. https://doi.org/10.2113/gseegeosci.16.3.257
62. Kim B, Sanders BF (2016) Dam-break flood model uncertainty assessment: case study of extreme flooding with multiple dam failures in Gangneung. South Korea J Hydraul Eng 142:05016002. https://doi.org/10.1061/(ASCE)HY.1943-7900.0001097
63. Lang J, Alho P, Kasvi E et al (2019) Impact of Middle Pleistocene (Saalian) glacial lake-outburst floods on the meltwater-drainage pathways in northern central Europe: Insights from 2D numerical flood simulation. Quaternary Sci Rev 209:82–99. https://doi.org/10.1016/j.quascirev.2019.02.018
64. Waters S, Aggidis G (2016) Tidal range technologies and state of the art in review. Renew Sust Energ Rev 59:514–529. https://doi.org/10.1016/j.rser.2015.12.347
65. van der Horst D (2007) NIMBY or not? Exploring the relevance of location and the politics of voiced opinions in renewable energy siting controversies. Energy Policy 35:2705–2714. https://doi.org/10.1016/j.enpol.2006.12.012
66. Breukers S, Wolsink M (2007) Wind power implementation in changing institutional landscapes: an international comparison. Energy Policy 35:2737–2750. https://doi.org/10.1016/j.enpol.2006.12.004
67. Ciupuliga AR, Cuppen E (2013) The role of dialogue in fostering acceptance of transmission lines: the case of a France-Spain interconnection project. Energy Policy 60:224–233. https://doi.org/10.1016/j.enpol.2013.05.028
68. Wolsink M (2010) Contested environmental policy infrastructure: Socio-political acceptance of renewable energy, water, and waste facilities. Environ Impact Asses 30:302–311. https://doi.org/10.1016/j.eiar.2010.01.001
69. European Commission (2022) Environment - Natura 2000. https://ec.europa.eu/environment/nature/natura2000/index_en.htm. Accessed 23 Nov 2022
70. (2014) Directive 2011/92/EU of the European Parliament and of the Council of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment (codification) (Text with EEA relevance)
71. Bergström L, Kautsky L, Malm T et al (2014) Effects of offshore wind farms on marine wildlife—a generalized impact assessment. Environ Res Lett 9:034012. https://doi.org/10.1088/1748-9326/9/3/034012
72. Pérez Lapeña B, Wijnberg KM, Hulscher SJMH, Stein A (2010) Environmental impact assessment of offshore wind farms: a simulation-based approach. J Appl Ecol 47:1110–1118. https://doi.org/10.1111/j.1365-2664.2010.01850.x
73. van Adrichem S (2021) Influence of rapid draw down on dike stability. TU Delft
74. Higgins P, Foley A (2014) The evolution of offshore wind power in the United Kingdom. Renew Sust Energ Rev 37:599–612. https://doi.org/10.1016/j.rser.2014.05.058
75. Wei Y, Zou Q-P, Lin X (2021) Evolution of price policy for offshore wind energy in China: Trilemma of capacity, price and subsidy. Renew Sust Energ Rev 136:110366. https://doi.org/10.1016/j.rser.2020.110366
76. Jansen M, Staffell I, Kitzing L et al (2020) Offshore wind competitiveness in mature markets without subsidy. Nat Energy 5:614–622. https://doi.org/10.1038/s41560-020-0661-2
77. Huijts NMA, Molin EJE, Steg L (2012) Psychological factors influencing sustainable energy technology acceptance: a review-based comprehensive framework. Renew Sust Energ Rev 16:525–531. https://doi.org/10.1016/j.rser.2011.08.018
78. Burke DJ, O'Malley MJ (2011) Factors influencing wind energy curtailment. IEEE Trans Sustain Energy 2:185–193. https://doi.org/10.1109/TSTE.2011.2104981
79. Fürsch M, Hagspiel S, Jägemann C et al (2013) The role of grid extensions in a cost-efficient transformation of the European electricity system until 2050. Appl Energy 104:642–652. https://doi.org/10.1016/j.apenergy.2012.11.050
80. Matevosyan J (2007) Wind power integration in power systems with transmission bottlenecks. In: 2007 IEEE Power Energy Soc Gen Meet. IEEE, Tampa, FL, USA, pp 1–7
81. Moradzadeh M, Zwaenepoel B, Van de Vyver J, Vandevelde L (2014) Congestion-induced wind curtailment mitigation using energy storage. In: 2014 IEEE International Energy Conference (ENERGYCON). IEEE, Cavtat, Croatia, pp 572–576
82. Rasmussen MG, Andresen GB, Greiner M (2012) Storage and balancing synergies in a fully or highly renewable pan-European power system. Energy Policy 51:642–651. https://doi.org/10.1016/j.enpol.2012.09.009
83. Breeze P (2018) Hydrogen Energy Storage. In: Power System Energy Storage Technologies. Academic Press, pp 69–77
84. Hunt JD, Zakeri B, de Barros AG et al (2021) Buoyancy energy storage technology: an energy storage solution for islands, coastal regions, offshore wind power and hydrogen compression. J Energy Storage 40:102746. https://doi.org/10.1016/j.est.2021.102746
85. Campanile A, Piscopo V, Scamardella A (2018) Mooring design and selection for floating offshore wind turbines on intermediate and deep water depths. Ocean Eng 148:349–360. https://doi.org/10.1016/j.oceaneng.2017.11.043
86. Windt C, Goseberg N, Martin T, Bihs H (2021) Validation of a Numerical Model for the Investigation of Tension Leg Platforms With Marine Energy Application Using REEF3D. In: Volume 9: Ocean Renewable Energy. American Society of Mechanical Engineers, Virtual, Online, p V009T09A027
87. Itaoka K, Saito A, Akai M (2005) Public acceptance of CO2 capture and storage technology: A survey of public opinion to explore influential factors. In: Greenhouse Gas Control Technologies 7. Elsevier, pp 1011–1019. https://doi.org/10.1016/B978-008044704-9/50102-6
88. Azman A, Silva D, JL, Samah BA, et al (2013) Relationship between Attitude, Knowledge, and Support towards the Acceptance of Sustainable Agriculture among Contract Farmers in Malaysia. Asian Soc Sci 9:p99. https://doi.org/10.5539/ass.v9n2p99
89. Devine-Wright P (2015) Renewable energy and the public: from NIMBY to Participation, Earthscan from Routledge

90. Vaughan E, Seifert M (1992) Variability in the framing of risk issues. J Soc Issues 48:119–135. https://doi.org/10.1111/j.1540-4560.1992.tb01948.x
91. Porter SR (2004) Raising response rates: what works? New Dir Institutional Res 2004:5–21. https://doi.org/10.1002/ir.97
92. Kost RG, Correa da Rosa J (2018) Impact of survey length and compensation on validity, reliability, and sample characteristics for Ultrashort-, Short-, and Long-Research Participant Perception Surveys. J Clin Transl Sci 2:31–37. https://doi.org/10.1017/cts.2018.18
93. Helm D (2014) The European framework for energy and climate policies. Energy Policy 64:29–35. https://doi.org/10.1016/j.enpol.2013.05.063
94. Tol RSJ (2012) A cost–benefit analysis of the EU 20/20/2020 package. Energy Policy 49:288–295. https://doi.org/10.1016/j.enpol.2012.06.018
95. Polzin F, Migendt M, Täube FA, von Flotow P (2015) Public policy influence on renewable energy investments—A panel data study across OECD countries. Energy Policy 80:98–111. https://doi.org/10.1016/j.enpol.2015.01.026
96. Polzin F, Egli F, Steffen B, Schmidt TS (2019) How do policies mobilize private finance for renewable energy? A systematic review with an investor perspective. Appl Energ 236:1249–1268. https://doi.org/10.1016/j.apenergy.2018.11.098
97. Perlaviciute G, Steg L, Sovacool BK (2021) A perspective on the human dimensions of a transition to net-zero energy systems. Energy Clim Change 2:100042. https://doi.org/10.1016/j.egycc.2021.100042
98. Liu L, Bouman T, Perlaviciute G, Steg L (2019) Effects of trust and public participation on acceptability of renewable energy projects in the Netherlands and China. Energy Res Soc Sci 53:137–144. https://doi.org/10.1016/j.erss.2019.03.006

Publisher's Note