HDelivery

H-delivery WP 3 – Task 3.2: Characterisation of prospective technologies

Some initial methodological considerations in the development and design of Delphi Surveys

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Contents

Background

SUPERGEN XIV - Delivery of Sustainable Hydrogen brings together 12 of the UK's leading universities to jointly work on a range of research topics aiming to radically improve the way in which Hydrogen and hydrogen-based fuels are produced and delivered. Work Package (WP) 3 Socio-technical Analysis and Appraisal of Hydrogen Production brings together the engineering and socio-economic dimensions of the consortium's research. We aim to undertake rigorous interdisciplinary assessment and modelling of the potential for novel and emerging technologies to contribute to the large-scale delivery of sustainable hydrogen, and identify specific recommendations for future research, policy and industrial development.

Introduction

This paper contributes to H-Delivery Task W3.2: Technology Characterisation. It provides an overview of the development and uses of the Delphi methodology in the field of energy. It aims to highlight key issues and considerations to be taken into account when designing and implementing a Delphi study. A sister paper will consider the results of low carbon energy studies and their relationship to the future of hydrogen energy.

This paper will introduce the aims and mechanism of the Delphi survey. Information on organising a Delphi survey has been summarised to include the overall plan, structuring the survey and questions, choosing participants and disseminating the survey. Some examples of Delphi surveys being combined with other analysis methods are discussed, along with potential issues and pitfalls. This is followed by a short section on how the results of Delphi surveys (and individual rounds) can be presented. Finally the "Endpoint" of a Delphi survey is covered.

Delphi Background

The Delphi method aims to distil the judgement of experts through successive iterations of a questionnaire. Feedback from each round is disseminated to the participants to take under consideration for the next round. The process can reveal convergence of opinions and identify conflicting views [1]. The questionnaire is posed anonymously and includes feedback from previous rounds when the questionnaire is revisited. The anonymity of the process allows participants to change their position in light of new information without having a public opinion to defend. It also reduces the tendency of people to herd behind the answer given by a particularly respected person in the area.

The Delphi method is considered especially useful for long range predictions (20 – 30 years) as expert opinions are often the only source of available information over that timescale. At its best the Delphi survey can influence the future, rather than forecast it. It is also considered to promote learning among panel members and the monitoring team.

Delphi was originally introduced and practiced to deal with technical topics and seek consensus among homogeneous groups of experts. RAND Corporation is usually

acknowledged as having conducted the earliest Delphi studies in the 1950-60s [1]. However, the conventional Delphi study was subject to a wave of criticism in the mid 1970s resulting in redefinement of some principles. In particular, there is less focus on consensus seeking, as this has been seen to alienate participants and ignore important information.

Variants have been developed from the basic technique. The Policy and Argument Delphis can be used to explore different views on major policy issues. This type of application should include scientists (experts on facts), decision-makers (experts in use of resources) and synthesisers (experts on the whole picture or relevancy). Whilst the Disaggregative Policy Delphi constructs alternative scenarios from the issues being studied, and uses these scenarios to create clusters of participants with similar views to provide more of a context to the specific statements from the survey.

Planning a Delphi survey

The key steps in designing and implementing a Delphi study can be summarised as follows:

- define aim of survey
- define scope of survey (economic / technological push / social pull / environmental)
- literature survey (identify significant driving forces, variables, trends)
- select experts
- draft survey (include introduction to study purpose and competence check for each question)
- test draft survey (~10 participants – these responses can be included in the analysis of round 1)
- finalise survey
- issue to round 1 participants
- alter in light of round 1 responses and include new information arising from answers
- issue to round 2 participants – request justification of answers falling outside of interquartile zone established in round 1
- repeat previous 2 stages as often as necessary
- carry out final analysis
- present results

Survey Structure

Whilst obviously individual Delphis vary in the design of the survey tool used, a generic structure would generally follow the pattern set out below.

Introduction
Set the scene for the survey – explain the aims and give any general information which will help the participant. Also give information on the likely time required to fill in the survey.

Section 1 – profile

Participants give information on their area of expertise, professional background, demographic profile and are given an option for their e-mail address.

Section 2 – landscape
Opinion of the sector and key drivers of the technology – set within the scope of the survey. Include a competence check for each section.

Subsequent Sections
The following sections may deal with individual technical issues, societal trends, economics, regulation, policy, international context or any other area of interest to the survey. Societal trends may include such aspects as transport, spatial movements, future social relations, future work, demographic trends and environmental restraints.

Include a competence check for at least each section, it may be preferable to include a competence check for each question if they cover a wide range of expertise. Participants should be given the option of omitting all or part of a section should they choose.

Barriers, and Wildcards
It may be beneficial to explore participant views on potential barriers to the visions/scenarios taking place. This could even include 'out of the blue' wildcard issues or disruptor technologies with the capability of derailing the trends which are currently being followed.

Frameworks
Suggesting different policy/economic/social frameworks can help people to think of options which are outside of their current expectations.

Question Structure

The Delphi survey is often put in the format of a statement, followed by questions referring to the statement. It is important that the statement is concise and unambiguous. Examples are [2]:

- 50% of vehicles in European Union produce zero emission (other than CO_2 and water)
- Reduction in capital cost of offshore platforms by 50% compared with best practice today for similar fields
- Practical use of Ni based super alloys capable of continuous operation 60^oC higher than the current best

Each issue should be treated separately as combining them in one statement can lead to confusion.

Questions referring to the statement should also be clear. An example when discussing development of new technologies would be to differentiate between laboratory scale, first practical application and wide diffusion in the market.

An alternative method is to set open ended questions. Examples are [2]:

- List four trends or issues and their driving causes that you believe may influence the sector up to 2015

- Identify technologies, breakthroughs, scientific advances or innovations needed to underpin products, processes or services

Responses may be sought in terms of:

- Degree of impact (e.g. wealth creation, quality of life)
    - Harmful
    - Neutral
    - Beneficial
    - Highly beneficial
- Period within which the event will have first occurred
    - Time periods (5 / 10 yr bands including never)
- Necessity of collaboration
    - None
    - UK
    - European
    - Global
- UK current position in relation to other countries
    - Leading edge
    - Average
    - Lagging behind
- Constraints on occurrence
    - Social / ethical acceptability
    - Technological feasibility
    - Industrial / commercial
    - Lack of funding
    - Economical viability
    - Regulatory / policy / standards
    - Education / skill base

Etc

It is good practice to leave a comments space next to each section / question and to invite respondents to elaborate on their responses.

Participants

It is important to clearly define the expertise matrix required. This might require participants with specific detailed expertise as well as some with a broad overview. Appropriate participants are selected from different fields. These include:

- Policy specialists
    - Government representatives
    - NGO and interest group representatives
    - Planners
    - Economists
    - Energy Agencies
- Technical specialists
    - Academics
    - Researchers
    - Engineers
    - Planners

    - Environmentalists
    - Climatologists
- Industrial representatives
    - Energy consuming industries (chemistry, steel making, transport, etc)
    - Engineering companies
    - Utility companies
- Forecasting specialists
- Social specialists
    - Social scientists
    - Historians
- Users and potential users of proposed technologies

Technology 'users' are stakeholders of technology developments and may determine the success or failure of proposed technologies. The work of Tzeng et al [3] considered the views of bus users for their study on alternative fuels.

After key figures have been invited to take part many surveys recruit their participants using the 'snowball' method – asking the initial group to nominate others. This is limited by the tendency of people to nominate others similar to themselves (e.g. industrial people tend to nominate other industrial people, although academics were equally likely to nominate industrial people as other academics [2]). Another technique has been to keep inviting new participants to the study until no more new names come forward [1].

Appropriate academics can often be identified from the authors of relevant publications or speakers at appropriate congresses. A project website can be used as a central point for volunteers to join the survey. Any fields which are not represented can be completed through direct research (internet, address databases, etc).

It would be advisable to include 'naysayers' among the participant population. They are likely to raise topics which may be considered insignificant by the other participants but which may be viewed as important by people outside the community.

Drop out
Many surveys have experienced significant 'drop-out' of participants at different stages of the process. The drop out levels for a selection of Delphi surveys can be found in

Table 1.

Table 1 - Indication of Delphi Survey drop out rate

Survey	Round 1		Round 2	Round 3
	Participants invited	Responses	Responses	Responses
Valette et al [4]	250	86	56	39
Georghious [2]	8384 (over 15 panels of which 1 referred to energy)	2585	1060	
Wilenius & Tirkkonen [5]	142	98	2 group discussions of 20 people	2 group discussions of 20 people
Iniyan et al [6-8]	300	151	72	n/a
Wehnert et al [9]	3461	668	418	
Gough [10]	242	88	Workshop with selection of original participants and additional stakeholders	
Brent & Kruger [11]	91	7		
Al Saleh [12]	35	33	27	32
Terrados et al [13]	13	9		

In some surveys, the responses of participants who did not complete all stages have been completely eliminated from the analysis. However, this could be a dangerous precedent to follow. It is acknowledged that some participants fail to complete all the rounds because they feel their responses are not being acknowledged, by eliminating their responses valid points are likely to be lost entirely.

Degree of expertise

The criteria for selecting participants can differ between surveys. The most appropriate definition of suitability is "sufficient expertise to answer the questions posed" [2]. However, it is often equally important to ensure that specific sectors or geographic regions are represented.

Depending on the scope of the survey, it may be more important to check the confidence of the respondent to answer each section / question than to obtain their overall qualifications / experience in the field. This opens the possibility of checking 'experts' response against the general response for particular topics.

A scale of expertise which has been used in more than one survey [2]is:

1 – unfamiliar with the topic (respondents who tick this are less likely to complete the section on this topic)
2 – casually acquainted (have read or heard about the topic in media or other popular presentations)
3 – familiar with the topic (know most of the arguments advanced for and against some of the issues surrounding it and have formed some opinion about it)
4 – knowledgeable in the topic

A – expert in it some time ago, but feel somewhat rusty now
B – in the process of becoming an expert, but still have some way to go to achieve mastery of the topic
C – work in a neighbouring field and occasionally draw upon or contribute to the development of this field

5 – expert (consider yourself to belong to the community of people who currently dedicate themselves to the topic matter

A – concerned with markets, commercial markets or needs in the area – recognized outside your organization as having a strong grasp of future market and business trends or of regulatory and other aspects
B – technical – are likely to have presented, written up and/or published the results of your work or may hold patents for its application

Demographics

Those surveys which have carried out a demographic analysis of their respondents have found them to be overwhelmingly male, with a significant number of respondents aged over 50 [2].

Distribution methods

Traditionally the participants of Delphi surveys have been asked to complete paper surveys distributed by post. However, this increases the time taken and increases the amount of time and consumables required to implement a survey. An improvement on this is to replicate the postal system using e-mail; however, it is now possible to use internet based survey programmes which can automatically monitor responses and control mail shots. Assessments of a number of internet based survey programmes follows:

Armstrong

(http://armstrong.wharton.upenn.edu/delphi2/)
Although this has been developed specifically for Delphi surveys it has limited flexibility for question types and participant contact. It facilitates a limited amount of analysis on-line; however, it does not have a professional image which may discourage potential participants. Although there is no charge for using the facility, it is not recommended.

Bristol Online Survey

(http://www.survey.bris.ac.uk/)
This has been used for Delphi Studies by staff at BRASS, Cardiff University. Although they felt it was satisfactory for the purpose, its lack of flexibility in layout of questions was noted. This facility costs £500 +VAT per year.

Calibrum

(www.calibrum.com/Products/Surveylet/Login.asp)
This has significant flexibility in question types, including the facility to link questions allowing the survey to be tailored depending on respondent's answers. In addition Calibrum accommodates multiple survey rounds. The facility has a variety of options for contacting respondents and responses can be exported to Excel, it also allows results to be published on the web. Calibrum can used at a cost of $0.50 per response. Further support is available at an additional charge.

Lime Survey

(http://www.limesurvey.org/)
This has been used for a Delphi Study by staff at BRASS, Cardiff University. It has been found to have significant flexibility in question types, including the facility to link questions allowing the survey to be tailored depending on the respondent's answers. This facility has a variety of options for contacting respondents and responses can be exported to Excel and SPSS for further analysis. There is no charge for using the facility.

Real Time Delphi

(www.realtimedelphi.com/library/rtd_sales.php)
There is a charge of $5000 for a single "standard format" study; however, this includes one day of consultancy to facilitate the design process. This facility is suitable for "real time" Delphi and does not support survey rounds.

Survey Monkey

(www.surveymonkey.com)
This website has a professional appearance and can accommodate a wide range of question types. It also provides a progress indicator to the respondent. Survey Monkey has a variety of options for contacting respondents and responses can be exported to Excel for analysis. There is an annual subscription of £200.

The final choice of vehicle for an on-line Delphi survey will depend upon the flexibility required to pose complex question types.

Face to face / Telephone Interviews
There is concern [14] that the anonymity of the basic Delphi can lead to a lack of accountability of opinions. This has been tackled in some studies [15] by interviewing the participants rather than sending surveys. Such interviews can be semi-structured to allow participants to add novel questions and statements. However, if only one round of interviews is being planned, it is essential that pilot interviews are undertaken. Care should also be taken to use a highly informed interviewer who can instigate a broad and detailed exchange with early interviewees (before other interviewees have had the opportunity to make contributions to be discussed). It is vital that the interviewer is able to judge vague answers from one interviewee against the more defined answers of other interviewees, for this reason the use of more than one interviewer should be avoided

Combinations of Delphi and other techniques

The Delphi survey can be run in conjunction with other techniques. In some instances the techniques can run in parallel, but more commonly they are run sequentially.

Parallel

Some studies have carried out other activities e.g.:

- scenario construction in parallel with one round of the Delphi study [15], allowing the information to be fed into subsequent rounds.
- A set of questions issued only to a subset of the respondents to provide information. In particular, this method has been used [15] to compare the responses of futurists and historians, where historians can consider the validity of an issue in the past and it's likely future applicability.
- Workshops with subsets of participants from different geographical areas or interest backgrounds [2].

Non–parallel

The anonymous survey based Delphi can be used in conjunction with group discussions. In some instances [5, 9] the Delphi survey is used to identify issues for the group discussion, but the opposite can also hold true [16]. Some studies have invited non-participants as well as participants to group discussions held after the Delphi Study [1].

Another option is to carry out a SWOT analysis of the situation and assess the alternatives generated by this through the Delphi survey. The SWOT analysis considers strengths, weaknesses, opportunities and threats [13].

Scenario Building

The information derived from the Delphi can be used to develop a future scenario. A scenario should be plausible, relevant and internally consistent. The scenarios can assume that society is going to develop in a particular way based on [17]:

- Assumed population / population distribution
- Assumed technology policy
- Assumed environment (e.g. deforestation / desertification)
- Assumed priorities (e.g. individual choice, ecological balance, social equity)

The scenarios are used to divide participants into 'opinion clusters' [1].

Multi-Criteria Decision Making Analysis (MCDM)

A number of MCDM methods exist [3, 13, 18]. These include:

- Analytical Hierarchy Process (AHP) – pairwise comparison method
- Elimination and Choice Translating Reality (ELECTRE) - based on rankings between pairs of alternatives
- Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE)
- Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) – should be applied to data with a normal distribution and small standard deviation unless sensitivity analysis will be included

- Goal programming (GP)
- VIKOR – compromise ranking method

Tzeng et al [3] combined Delphi Surveys with TOPSIS and VIKOR MCDM to consider the most appropriate alternative fuel for buses. Initially the participants developed an appropriate weighting of eleven criteria then ranked eleven alternative fuels against diesel.

Terrados et al [13] combined SWOT analysis, Delphi Surveys and MCDM to consider the most appropriate combinations of renewable energy for a region (Jaén) within Spain. The MCDA was carried out to strengthen the final results suggested through the Delphi survey. Twelve criteria were defined which included technological, environmental and socioeconomic factors. Each of the twenty eight potential actions was assessed against each of these factors. The PROMETHEE method was used to perform the MCDA. This allowed the actions which had been suggested through the SWOT and Delphi survey to be prioritised.

Yuzugullu and Deason [18] provide a further example of combining Delphi and MCDM techniques. This time to structure a hierarchy of societal welfare criteria for the production of hydrogen.

Technology assessment

A survey of patents and publications for the previous 10 years was compared with the results from a Delphi survey technology assessment [19]. This aimed to establish the efficacy of the Delphi survey at identifying breakthrough technologies. Five of the technologies identified in the Delphi survey as emerging and important did not have correlating evidence from the analysis of patents and publications. This may be due to the technologies being kept classified or also due to lack of funding for research.

Delphi Issues / pitfalls

Reviews of early energy related Delphi surveys [14] have led to the conclusion that the results can be over optimistic due to a failure to identify technological and economic barriers. Participants are also unlikely to foresee catastrophes, crises or major technology breakthroughs [9]. However, these concerns apply to other forecasting methods. Uncertainty over the accuracy of oil supply predictions is considered to be an underlying factor which affects most energy related forecast exercises [14].

Some Delphi studies (e.g. the UK Technology Foresight Programme [2]) have chosen to tackle up to 80 topics. In retrospect, this was felt to be too many and had consequent effects on the response rate.

At least eight Delphi pitfalls can be identified in conducting the Delphi technique [1]:

- biased selection of the panellists
- disregarding organisations
- forgetting disagreements
- ambiguous questionnaires
- oversimplified structured inquiry

- feedback reports without analysis
- forgetting the arguments
- lack of theory.

Delphi analysis / presentation

Quantitative responses

A number of statistics can be used to analyse quantitative responses:

- Number of responses for the question
- Median / mean / mode
- Interquartile range
- Skewness
- Shift in response (mean, standard deviation, etc) from round to round
- Rank correlation coefficient

Quantitative responses particularly lend themselves to being presented in graphical form (e.g. histograms). This is particularly useful when checking for 'double peaks' which would be lost if only more typical statistical information was used.

Open responses

Although there is no prescribed way to analyse / present open responses, the most important information is often found here, and care should be taken to preserve the information. This is particularly true of comments related to quantitative responses. One method to assess this type of response is to create classifications which similar responses can be assigned to.

It is possible to present some open responses in figures. Some methods used include time plans or graphs which use the axis to represent different scenarios.

End point

Initially Delphi surveys were iterated until a consensus between the participants was reached. One particular study required the opinion to be held by three quarters of the participants to be considered a consensus [12]. However, this approach can result in the loss of valid points and the drop out of participants who feel that their opinions are not being acknowledged. A more recent approach has been to consider the stability of the responses – if the responses are not changing significantly, then it can be considered that the survey is complete. Capturing the information from the remaining disagreements may be more important than forcing an un-natural consensus.

References

1. Rikkonen, P. and P. Tapio, *Future prospects of alternative agro-based bioenergy use in Finland - Constructing scenarios with quantitative and*

qualitative Delphi data. Technological Forecasting and Social Change, 2009. **76**: p. 978-990.
2. Georghious, L., *The UK Technology foresight programme.* Futures, 1996. **28**: p. 359-377.
3. Tzeng, G.-H., C.-W. Lin, and S. Opricovic, *Multi-criteria analysis of alternative-fuel buses for public transportation.* Energy Policy, 2005. **33**: p. 1373-1383.
4. Valette, P., et al., *Analysis of a delphi study on hydrogen.* International Journal of Hydrogen Energy, 1978. **3**: p. 251-259.
5. Wilenius, M. and Tirkkonen, *Climate in the making: Using Delphi for Finnish climate policy.* Futures, 1997. **29**: p. 845-862.
6. Iniyan, S. and T.R. Jagadeesan, *A comparative study of critical factors influencing the renewable energy systems use in the Indian context.* Renewable Energy, 1997. **11**(3): p. 293-317.
7. Iniyan, S. and T.R. Jagadeesan, *Effect of wind energy system performance on optimal renewable energy model - an analysis.* Renewable and Sustainable Energy Reviews, 1998. **2**: p. 327-344.
8. Iniyan, S. and K. Sumathy, *The application of a Delphi technique in the linear programming optimization of future renewable energy options for India.* Biomass and Bioenergy, 2003. **24**: p. 39-50.
9. Wehnert, T., et al., *European Energy Futures 2030*. 2007, Berlin: Springer.
10. Gough, C., *State of the art in carbon dioxide capture and storage in the UK: An expert's review.* International Journal of Greenhouse Gas Control, 2008. **2**: p. 155-168.
11. Brent, A.C. and W.J.L. Kruger, *Systems analyses and the sustainable transfer of renewable energy technologies: A focus on remote areas of Africa.* Renewable Energy, 2009. **34**: p. 1774-1781.
12. Al Saleh, Y., *Renewable energy scenarios for major oil producing nations: the case of Saudi Arabia.* Futures, 2009. **41**: p. 650-662.
13. Terrados, J., G. Almonacid, and P. Perez-Higueras, *Proposal for a combined methodology for renewable energy planning. Application to a Spanish region.* Renewable and Sustainable Energy Reviews, 2009. **13**(8): p. 2022-2030.
14. Utgikar, V.P. and J.P. Scott, *Energy forecasting: Predictions, reality and analysis of causes of error.* Energy Policy, 2006. **34**: p. 3087-3092.
15. Glenn, J., *The Millennium Project: Issues and Opportunities for the Future.* Technological Forecasting and Social Change, 1999. **61**: p. 97-208.
16. Saritas, O., E. Taymaz, and T. Tumer, *Vision 2023: Turkey's national Technology Foresight Program: A contextualist analysis and discussion.* Technological Forecasting and Social Change, 2007. **74**: p. 1374-1303.
17. Rohatgi, K. and P. Rohatgi, *Delphi as a tool for identifying future appropriate technologies in India.* Technological Forecasting and Social Change, 1979. **14**: p. 65-76.
18. Yuzugullu, E. and J.P. Deason, *Structuring objectives to facilitate convergence of divergent opinion in hydrogen production decisions.* Energy Policy, 2007: p. 452-460.
19. Bengisu, M. and R. Nekhili, *Forecasting emerging technologies with the aid of science and technology databases.* Technological Forecasting and Social Change, 2006. **73**: p. 835-844.