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WP5	Data analysis and interpretation

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Disclaimer

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EXECUTIVE SUMMARY

Overview

The context of this report is the FCH-JU project 'Hyacinth', which is investigating the social acceptance of hydrogen fuel cells (FCHs) in Europe. In Hyacinth, social acceptance is taken to include a range of actors in the innovation systems of stationary and mobile FCH applications, with an emphasis on publics, R&D actors and policy stakeholders. Hence social acceptance is here understood in the broad sense of societal embedding and adoption of technology, which involves many stakeholder groups and not simply the public. To cover acceptance broadly we therefore conducted a comparative study on the opinions and assessments of various stakeholders, from both the public and the private sectors, in several European countries. This report focuses on the analyses of these stakeholders' views and it uses a mixed methods design based on qualitative interviews and a questionnaire online survey with experts and members of stakeholders groups in five EU countries: France, Germany, Spain, Slovenia, and United Kingdom. Specifically, this study consists of:

- An online survey implemented with energy stakeholders and hydrogen experts (n=333).
- Semi-structured interviews with members of the stakeholders groups around selected hydrogen demonstration cases (n=145).

The objective of the study is to understand the innovation systems for selected mobile and stationary FCH technologies, particularly in terms of the expectations and perceptions of actors involved, and particularly in terms of what stakeholders think needs to change for FCH technologies to advance. In parallel a public survey was conducted across Europe. The results of this survey can be found in a separate report.

The data for both studies was collected in Spring 2016. The survey focused on stakeholder perceptions of hydrogen technologies, with a specific focus on two applications, small stationary hydrogen fuel cells on the one hand and hydrogen fuel cell electric vehicles (FCEVs) on the other hand. Furthermore it measured how actors in the innovation system perceive each other and the influence that this has on their decision-making.

Participants were recruited from large directories drawn together by the project partners with the intention to gain a representative share from the hydrogen community. The survey was implemented online and participants received invitations (and reminders) by email.

The interviews asked selected stakeholders for their views on FCH based on their involvement with ongoing or recently finished demonstration projects, thus, there experience related to specific cases. This included stationary and mobile FCH applications, as well as hydrogen supply for these. Interviewees had affiliations with public and commercial research and development organisations, as well as central and local government. They were identified via the databases on projects of Hyacinth consortium partners and approached by email and phone.

Both stakeholder studies were able to draw together heterogeneous and broad samples regarding fields of expertise and organizational affiliation and are likely to provide a good coverage of the hydrogen community, however, this cannot be proven as the attributes of the population under study are not known. In both studies the samples from Slovenia are small, those country-specific results for Slovenia have to be interpreted with caution.

Results

Stakeholder survey

- Of the participating stakeholders 88 % think that FCH are a good or a very good solution for energy and environmental challenges. Participants from the different countries do not differ in this evaluation.
- Regarding specific FCH technologies and applications, the most positive expectations are revealed for H2-buses and H2 as a means of storage for renewable energy, followed by H2-based back-up power systems. Least positive prospects are voiced for large scale systems for prime power. Looking at the results in more detail on a country level, respondents from France are most positive on average, followed by the UK and Germany with Spain and Slovenia ranging behind. Some of these differences are statistically significant often confirming more positive attitudes in Germany or France compared to Spain or Slovenia. Overall participants from all countries favour further governmental support.
- For the remainder of the questionnaire, participants had to choose between answering further questions either on fuel cell stationary applications for heating and electricity or on H2 powered vehicles (FCEVs) representing fuel cell transport applications and related infrastructures. In all countries but Slovenia the majority of participants chose thetransport application, overall 72 %. The choice of application appears to be related to the evaluation of this application and respondents tend to choose the application they are more optimistic about.

Fuel cell stationary applications for heating and electricity

- Due to the limited sample size, cross-country comparisons were not run for this application type. Overall, respondents rate their familiarity with stationary applications as medium.
- Regarding challenges for stationary applications, safety issues and technological maturity are seen as minor challenges with cost disadvantages as the major one. Other challenges like awareness by different groups of actors, incentives, H2 production etc. range in between. Overall they were all rated around the scale mean, i.e. neither being an extremely serious issue nor a negligible one. Further comments inserted by the participants have an emphasis on issues referring to the innovation system in general. In comparison with other heat- and power systems or renewable technologies for electricity and heat respondents are perceived as competitors to some extent.

- Overall, respondents state that it will influence public acceptance whether H2 is green and that business models for an H2 distributions infrastructure are needed and that air quality regulations might be relevant.
- Regarding public funding for FC-technologies respondents were more positive about funding research and development than the funding for demonstration project and least positive about subsidies on purchase prices.
- Professionals from the same sector and researchers are rated as having a high familiarity, significantly higher than all other groups. Politicians' and industrial/ commercial users' familiarity is regarded as higher than the one in the public. The public's familiarity is rated lowest. Similarly, the attitude of both the research sector and professionals from same sector is regarded to be higher than the attitude of the other three groups. Familiarity and attitudes are rated similarly to some degree, i.e. in case of higher familiarity the rating of attitudes tends to be higher as well.

Fuel cell transport applications and related infrastructures

- Again, as for stationary applications, respondents rated their familiarity with FCEVs as medium with similar answering patterns across countries.
- Providing a sufficient infrastructure of refuelling points is seen as the greatest challenge, followed by costs. Safety is rated as the least challenge. Other issues like technological maturity, regulation, H2-production rank in between. Some country differences are detected in the rating of challenges, most often German participants evaluate a specific challenge as less serious than one of the other countries. Most of the additional challenges mentioned by the participants refer to the innovation system again.
- Participants favour FCEVs over all other drive train technologies listed. However, the highest advantage is ascribed in comparison to conventionally powered vehicles and is smallest in comparison with BEVs. Country differences are small. Regarding state support for FCEVs, respondents rated the installation of hydrogen refuelling points as a top priority along with funding research and development and considering demonstration projects significantly less important and subsidies for the purchase of FCEVs even less relevant.
- The highest level of familiarity is ascribed to professionals from the same sector and researchers, the public is perceived to have the lowest level of familiarity. From the attitudinal perspective, the two groups most familiar are also perceived to have more positive attitudes than politicians and regulators, the general public and the automotive sector. Familiarity and attitudes are rated similarly to some degree, i.e. in case of higher familiarity the rating of attitudes tends to be higher as well. Some country differences emerge, mainly including lower ratings from Spanish participants compared to some of the other countries.

Predictors of market development

- For stationary applications, the degree to which they are perceived to be able to compete with renewable electricity and heat technologies is most strongly related to the expected market development for FCH-systems. In addition to this, the implementation of air quality regulations and the development of business models for H2 distribution infrastructure are also associated with more positive market development.
- For transport applications, five factors are predictive of the rating on market development: competition from alternative technologies, competition from full electric cars as well as CNG / LNG cars, attitudes of professionals from the same sector and from actors from the automotive sector.

Stakeholder interviews

Interviewees were asked for their perceptions of the strengths and weaknesses of the FCHs and/or hydrogen as an energy vector; their expectations of how the sector would develop; and their corresponding recommendations. Beyond this, the specific objects of their comments were self-selected: we have allocated interviewee comments post-hoc to the broad categories of hydrogen per se, stationary applications and transport applications, for ease of comprehension. The terms ‘strengths’ and ‘weaknesses’ were also left to the interviewee to define in ways that made sense to them. Interviewee comments are not evaluated for their veracity: the aim is to represent the variety of views among those actively involved with FCHs in a range of contexts.

Interviewee sample description

The respondents came from, in rank order of within-country percentage share: university and state research organisations, particularly in Spain; local government, particularly in Germany and the UK; multi-sector partnerships (mixed affiliations), particularly in the UK and France; and commercial organisations, particularly in Slovenia.

Perceptions of hydrogen supply and use

- The environmental performance of hydrogen is seen as the key strength, despite the scepticism of many regarding the inefficiency of combining multiple conversion processes. In addition, another dominant strength of hydrogen is perceived as its versatility, especially its utility as an energy storage vector for renewable energy supply, both per se and in relation to electrical grid balancing.
- The key perceived weakness of hydrogen is overwhelmingly seen as its cost, followed by inadequate or excessive regulation; lack of markets and market acceptance is also mentioned repeatedly
- The key expectations for hydrogen are mixed: the majority of interviewees take a generally positive view of its prospects, with market development expected by many in the relatively near term, albeit with national differences and specificities. At the same

time, however a considerable number of interviewees perceive an uncertain future for hydrogen and a high degree of conditionality on government policy support.

- Interviewees focussed on hydrogen supply and use made many recommendations, of which by far the most frequent was that more government and political support is required; followed by a perception of the need to inform and engage stakeholders, together with additional R&D to reduce costs.

Perceptions of fuel cell stationary applications for heating and electricity

- Interviewees strongly emphasised the utility of FCHs for portable / uninterruptible power as a key strength. To a lesser extent, reliability and efficiency as well as positive perceptions and environmental advantages were also emphasized, with German respondents being dominant in those categories.
- Interviewees overwhelmingly cited cost as the key weakness of the stationary applications. Secondly, the complexity of the system as well as limited awareness and support by regulators and governmental stakeholders are mentioned. These were followed by several weaknesses at similar frequency of occurrence and included for example inefficiency of the system, the challenge of finding commercial partners and perceived and 'actual' safety.
- The tone of expectations was mixed and seems to relate to the national policy environment. While unqualified positive expectations were voiced as often as negative ones, the unqualified negative expectations came only from Spanish interviewees, where interviewees feel unsupported by national policy despite holding positive perceptions of the technologies per se. Qualified positive expectations came from a mix of countries. Low expectations in the short to medium term formed the third largest fraction of responses (again dominated by Spain and also Slovenia); this was followed by expectations expressing a positive view on near-term market development for the technology from various countries.
- Interviewees' main recommendation was for more sustained and coherent Government (including European-level) support. Bracketed together, this appeal for Government support dominates. Appeals for enhanced regulatory and public support and understanding follow, with regulatory support particularly relating to issues of safety. In short, most of the recommendations are for supportive governmental action.

Fuel cell transport applications and related infrastructures

- The top strengths of mobile FCH applications are focused on technical performance: long range, short refill times, high torque, etc. A further emphasis is on lack of local emissions or that the technology is generally good also compared to alternatives
- Financial cost dominates in terms of perceived weaknesses, followed by limited awareness and support by regulators and government and competition with other technologies; lack of infrastructure including fuel.

- Interviewees were divided in the tone of their expectations, with many expressing positive, general expectations but many also pessimistic in the short to medium term. Within these, UK interviewees expressed more general optimism than pessimism and Spanish interviewees the converse. More specific expectations all had – in comparison - very low incidental numbers.
- Interviewees again recommended governmental, political and regulatory support, including support leading to cost reductions; investment in refuelling infrastructure together with more communication and engagement generally and of publics were also advocated.

Overall, the interviews indicate an appreciation of and enthusiasm for the potential of hydrogen technologies and hydrogen as an energy vector, principally for the potential environmental and also specific operational benefits (long range or longevity of power output relative to batteries and also storage functions), but equally an awareness that the high costs of FCH system components render the future of the technologies particularly uncertain.

Countries and country groupings

In earlier deliverables of this project a categorization was proposed that Germany and UK are countries, where there is an advanced hydrogen support; France and Spain are countries with medium hydrogen support; and Slovenia has a low hydrogen support level. Overall country differences in the survey are small as emerging patterns tend to be highly similar and differences small in numbers. To some extent, this also applies to the interview study, nevertheless, this method is more sensitive to differences in this case. German stakeholders tend to paint a comparatively optimistic picture and Slovenians being comparatively less optimistic, i.e. these two countries seem to confirm that their placement at different ends of a continuum is appropriate. However, the situation is more complex for the remaining countries with e.g. Spanish respondents being very pessimistic as well. In France, perceived levels of relatively low social acceptance coincide with positive market expectations. And the UK seems to be shaped by heterogeneous perceptions.

Conclusions and Recommendations

There are no strong signals that FCH technologies are yet breaking out of their niches into the mainstream ‘regimes’ of fuel supply and provision of mobility and heat and power. However, it is notable that this perception varies across countries and is to some extent associated with differing levels of government investment in R&D programmes (Germany and Spain being apparently at opposite poles). Overall, while the R&D stakeholders have a strong positive appraisal of FCH technologies, they perceive cost and limited regulatory, political and commercial support in addition to competition from other technologies as key, inter-related obstacles. Consequently, again despite the perceived benefits, stakeholders generally view these as likely to be realised in the medium to long term rather than near term. Nonetheless, FCH technologies are also perceived as offering some realistic niche potential in the shorter term, specifically uninterruptible power, auxiliary power and high power demand such as fork lifts and heavy goods vehicles. Lack of public support is not to be expected to become a major challenge if the framework conditions for the technologies develop in a supportive way.

More specifically we see as key take aways from the stakeholder survey that

- A majority of stakeholders considers that FCH technologies are positive for the environment
- FCH technologies are perceived as mature technologies
- From scepticism to expectance: social perception of FCH technologies is low but evolving
- Financial cost is perceived as the main weakness
- Inadequate/ excessive regulations are still a challenge – mirroring limited awareness by government:
- Stakeholders still claim more general (political) support
- Communication and engagement are a precondition

Translating this into policy recommendations this means

- There is a need for more sustained and coherent Government (including European-level) support. On the one hand, this implies a close link to carbon reducing policies, on the other hand support leading to cost reductions is needed.
- The installation of reliable hydrogen refuelling stations is a key precondition for the diffusion of FCEV.
- Securing green hydrogen is crucial
- Further demonstration projects and communication campaigns are a pre-condition to enhance social acceptance to the levels needed for market acceptance

Abbreviations

ANOVA	ANalysis Of VAriance
BEV	Battery Electric Vehicle
CHP	Combined Heat and Power
CNG	Compressed Natural Gas
CSA	Coordination and Supporting Action
DX.Y	Deliverable X.Y
EC	European Commission
FCCHP	Fuel Cell Combined Heat and Power
FCH	Fuel Cell and Hydrogen
FCH	Hydrogen Fuel Cell
FCH-JU	Fuel Cell and Hydrogen – Joint Undertaking
FCEV	Fuel Cell Electric Vehicle
IPR	Intellectual Property Rights
LNG	Liquefied Natural Gas
m-CHP	micro Combined Heat and Power
SAMT	Acceptance Management Toolbox
TC	Technical Committee
TIS	Technology Innovation Systems
WP	Work Package
WPL	Work Package Leader

1 Introduction

The HYACINTH project aims at gaining a deeper understanding of the social acceptance of fuel cell and hydrogen (FCH) technologies in Europe. Furthermore a tool to assist hydrogen project developers in thinking about the social acceptance factors of their projects and products, with the objective of supporting a more widespread use of these technologies in the future, will be developed.

This deliverable is part of *WP5 Data analysis and interpretation,* in which the findings of the empirical work are described. The empirical work carried out in this project includes two studies:

- ***Study 1. Public awareness and acceptance of FCH technologies***, based on a cross-sectional questionnaire survey with members of the general public in seven EU countries countries, namely Belgium, France, Germany, Spain, Slovenia, Norway, and United Kingdom.
- ***Study 2. Stakeholder acceptance, expectations and views of FCH technologies***, based on qualitative (semi-structured interviews) and quantitative data (via questionnaires) with members of the stakeholders groups in five EU countries, namely France, Germany, Spain, Slovenia, and United Kingdom.

The research concept and design for the surveys and interviews was developed as part of WP 3 (D3.1) as well as the questionnaires to the general public and selected stakeholders (D3.2). This WP drew on a context analyses developed in WP2 which – amongst others – looked into the policy background for FCH technologies in Europe and in the countries under study. This WP also proposed a grouping of countries into advanced (Germany, UK, Norway), medium (Belgium, France) and low (Slovenia). WP4 dealt with the data collection via quantitative (general public awareness and acceptance panel and selected stakeholders awareness and acceptance panel) and qualitative (stakeholder interviews) methods. This deliverable gives an overview on the results of the stakeholder study and will thereby also refer back to the proposed country groupings. The content of both deliverables from WP5 (D 5.1 and D 5.2) will feed into the Social Acceptance Management Toolbox (SAMT) to be developed in WP6.

The work on stakeholders in this deliverable is informed by innovation systems thinking and the socio-technical transitions literature that has developed from this. It is increasingly understood that the success of innovative energy technologies is dependent not only upon the technical characteristics of those technologies, but equally on supportive social, political and economic contexts (EC, 2014 and 2015; OECD, 2014). Moreover, the further understanding that the interconnections between policy domains requires mutually supportive policy mixes (Kern and Howlett 2009) is gaining ground more generally (OECD, 2014, 2015).

A technology innovation systems (TIS) perspective implies that we investigate the prospects for FCH technologies in an integrated way, identifying market, policy and regulatory barriers and drivers (Bergek et al. 2008). Analysis of a given system is undertaken systematically as part of a series of steps, e.g. identifying the structural components of the TIS, notably key actors, networks and institutions; the existence of modes and routes of knowledge development and diffusion; the nature of future expectations and signals, which influence the propensity of companies to invest; the extent of entrepreneurial experimentation; and the extent of market formation, i.e. the extent and nature of relevant markets to date.

In addition, sociotechnical transitions perspectives (e.g. Geels, 2004) add sustainability as an objective and are themselves gaining policy purchase for their recognition of the breadth of factors involved in sociotechnical change (e.g. OECD, 2014, 2015). Sociotechnical transitions perspectives emphasise the need for active policy intervention, governance and management, including policies for niche protection, i.e. supporting new technologies and associated network-building at an early stage (e.g. Vergragt, 2004). Sociotechnical analysts tend to advocate the design of fora that aim to foster an alignment of stakeholders – something that in practice can be difficult to achieve due to the way in which publicly funded and incentivised technology choices can affect organisations and individuals who have significant sunk investments. At the same time, while the aim of such approaches is to try to reduce opposition to change by incumbent 'regimes' by finding common ground and developing shared visions of the future, transitions analysts are well aware that political, economic and commercial interests may still be minded to strategically inhibit substantive change (e.g. Geels, 2014).

In this study, we comment on stakeholders' expectations, recommendations and perceptions of FCH technologies' strengths and weaknesses, not only per se, but also with a view to assessing the degree of alignment among stakeholders; and to better understand company directions of search (i.e. the priority that firms give to FCHs relative to alternatives) and technologies / innovations perceived as main competitors, the prospects and need for further policy and governmental support and the extent of markets to date. These and other insights provide an indication of the state of play and prospects for FCH technologies, as perceived by those closely involved in the FCH innovation system as of mid-2016 in the European countries considered. It is in this way that we examine the current and future state of societal acceptance of FCHs in the broad sense.

In the following, the results of the stakeholder study will be outlined and discussed after summarizing design and methods. Next, the findings from the first study, the survey will be presented. This is followed by the results from the second, the interview study. Overall results will be presented in a way that shows them on an aggregated European level as well as outlining national level findings in a comparative manner to direct the readers' attention to alignment and differences between nation states. We will then go back to the country level and the level of country groupings as proposed in WP2 in the next chapter and separately look at the five countries under study. A final concluding chapter closes this report.

2 Design and Methods

2.1 Design

The stakeholder study uses a mixed methods design: qualitative interviews and a questionnaire survey. The target group comprises of experts and members of stakeholder groups in five EU countries: France, Germany, Spain, Slovenia, and United Kingdom. The survey was implemented with energy stakeholders and hydrogen experts. The semi-structured interviews were carried out with members of the stakeholders groups around selected hydrogen demonstration projects. More details on research design and study scope of the stakeholder study are provided in deliverable 3.1 research concept.

2.2 Methods of data collection

Deliverables 3.1 and 3.2 presented the specific details of the research design, also including the questionnaire for the stakeholder survey and the interview guide for the stakeholder interviews. In this section the process of data collection how it finally took place for both the survey and the interviews is described.

2.2.1 Stakeholder survey

The stakeholder survey was conducted using an online questionnaire provided by Norstat. Data was collected from 30th March until 8th June 2016. The field time varied between 30 days for countries for which the required sample size was reached quickly (e.g. Germany) and 70 days for countries in which the recruitment was more difficult, e.g. because there are fewer stakeholders.

Invitations to take part in the survey were sent to participants by the project partners in each country. In total, 800 stakeholders were contacted by the project team, resulting in a sample of 333 participants (Table 1).

Table 1: Contacted stakeholders and sample sizes in each country

	Completes	***in % from Started***	***in % from Contacted***	**Started**	***in % from Contacted***	**Contacted**	**Share within sample %**
DE	127	*63*	*48*	202	*76*	265	38
UK	43	*57*	*33*	76	*59*	129	13
ES	78	*60*	*38*	129	*63*	204	23
FR	72+1*	*61*	*24*	118	*40*	294	22
SI	12	*55*	*23*	22	*42*	52	4
Sum	**332+1**	***61***	***35***	**547**	***58***	**944**	**100**

* In France one additional incomplete questionnaire which was nearly complete was added to the final data set.

The sample is unevenly distributed across the countries. The majority of respondents are from Germany followed by Spain and France while smaller percentages are from the United Kingdom and Slovenia. While a similar share of people across countries who started to answer the questionnaire also completed it (55-63 %), numbers seems to indicate some relationship between final sample size and share of participants: In Germany, the biggest share of respondents, also the highest percentage of people contacted completed the questionnaire while these values are lowest for Slovenia. This hints that the samples from the different countries are probably not fully comparable.

2.2.2 Stakeholder interviews

Interviews were conducted by the partners in each country. Interviews were carried out between 13th November 2015 and 8th June 2016. Most of the interviews were conducted by phone; some of them face-to-face. The interviews lasted between 15 and 90 minutes; most of them around 30 minutes.

2.3 Sample description

2.3.1 Stakeholder survey sample description

A total of 333 stakeholders took part in the survey. The highest percentage of response was registered in Germany, followed by Spain and France (Figure 1).

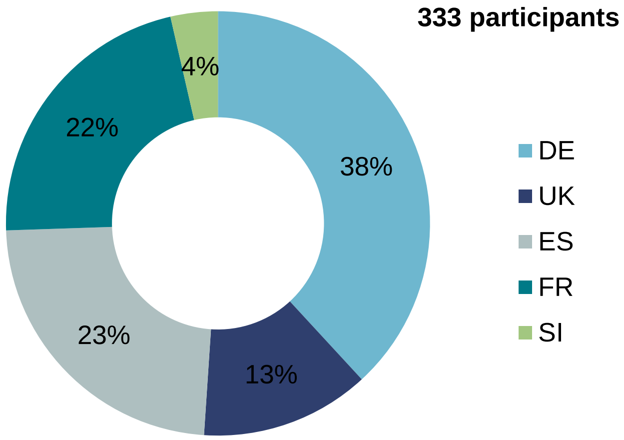

Figure 1 Sample size and country affiliation

In terms of organisational background the majority, 114 stakeholders, work in a private company; 57 stakeholders are from government organizations and 53 from other non-profit organizations (Figure 2).

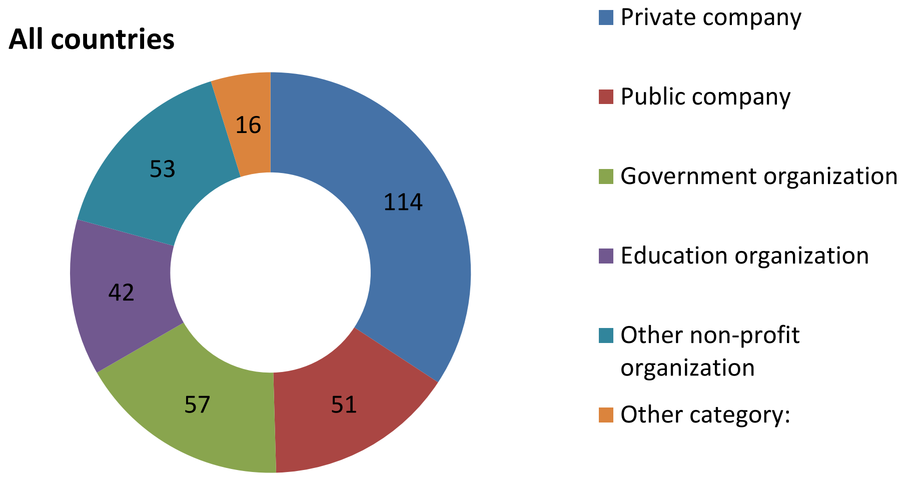

Figure 2 Type of organizations of stakeholders

Especially in France and Slovenia there is a high share of stakeholders from private companies (49 and 67 percent), whereas in Germany there are relatively many stakeholders from other non-profit organizations and public companies. In the UK, there are quite a lot (26 percent) of stakeholders from education organizations. The figures on the distributions on country levels are included into the annex (Appendix 1).

The stakeholders have plenty of experience in the field of hydrogen and fuel cells (cp. Appendix 1): More than a quarter of the respondents have been professionally involved in Hydrogen and/or Fuel Cell activities for 11 years or more, 26 percent are involved in these activities for less than five years and 21 percent for five to ten years.

With regard to the field of work or expertise, multiple answers were allowed. More than half of the respondents, 53 percent, state to work in research on hydrogen and/or Fuel Cells. Nearly a third works in the field of hydrogen production and a quarter in systems integrations (Figure 3).

	Frequency	% of sample	DE	UK	ES	FR	SI
Research on hydrogen and/or Fuel Cells	175	52,6	80	9	48	35	3
Fuel cell developer or manufacturer	47	14,1	26	4	15	1	1
Hydrogen production	98	29,4	32	7	37	22	
Professional services provider	60	18,0	29	7	12	12	
Policy development and program administration	61	18,3	28	14	7	10	2
Car manufacturer / OEM	16	4,8	12	1	1	2	
Systems integrator	84	25,2	42	3	25	11	3
Education, safety and training	57	17,1	21	6	16	13	1
Fuel cell user	49	14,7	24	7	13	5	
Hydrogen storage	51	15,3	21	4	16	10	
Service station operator	22	6,6	14	2	2	4	
Supplier to developer or manufacturer	11	3,3	2	2	2	5	
Commercialization support	25	7,5	8	6	7	4	
Fuel cell distributor or agent	8	2,4	3		3		2
Hydrogen distribution	15	4,5	3	4	4	4	
Other	45	13,5	14	11	9	8	3

Figure 3 Fields of work / expertise of participants

More than 40 percent are involved in hydrogen production and fuelling infrastructure, 31 percent in mobile-primary power and drivetrain. Further H2 applications a lot of stakeholders are involved in are small stationary applications (Figure 4).

	Frequency	% of sample	DE	UK	ES	FR	SI
No specific application	93	27,9	30	23	14	21	5
Small stationary (50KW or less)	94	28,2	38	4	30	18	4
Large stationary (more than 50KW)	59	17,7	24	4	14	16	1
Portable (including micro)	40	12,0	15	1	17	6	1
Mobile-Auxiliary power	45	13,5	12	2	20	11	
Hydrogen production and fuelling infrastructure	143	42,9	55	14	41	32	1
Mobile-primary power and drivetrain	103	30,9	57	9	24	12	1
Other	20	6,0	8	4	3	5	

Figure 4 FCH application / market participants are involved in

2.3.2 Interviewee sample description

This section describes the basic characteristics of those interviewed, in terms of affiliation, country and core interest. This is not a stratified, probability-based sample, but a purposeful sample focussed on scientific, commercial and policy stakeholders. Hence although the number of interviews is relatively large for a qualitative study, it nonetheless retains the typical characteristics of a qualitative study: it provides in depth information relative to a probability-based survey, here albeit on a relatively large scale, but the reader should be cautious about over-generalising when drawing inferences. This said, where themes recur repeatedly across respondents, one can at least assume that they merit attention and this is a key rationale for their quantitification below.

The following tables provide a summary of interviewee characteristics in terms of country and affiliation. Here we use aggregated affiliation categories for comprehensibility, broadly contrasting public, private, public research and non-profit affiliations, with the premise that each has different, if overlapping interests. The categories multisector partnership and other non-profit organisation were only used where this was the primary, i.e. their role was primarily to support an organisation of that type.

Table 2 gives the interviewee count by country and percentage of the total; it shows the uneven distribution of respondents, primarily reflecting differing levels of activity across countries, but also partly differing response rates.

Table 2 Interviewee count and percentage by country

	Germany	France	Spain	UK	Slovenia	Total
Count	34	37	39	24	11	**145**
Percentage	23	26	27	16	8	**100**

Table 3 gives interviewee sectoral affiliation category by country in absolute numbers and percentages. It shows a wide variation between countries in terms of the sectoral affiliation of interviewees.

Table 3 Interviewee organisational affiliation by country (count)

	DE		**FR**		**ES**		**UK**		**SI**		**Total**	
	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%
Other non-profit organization	1	3	0	0	2	5	3	13	1	9	**7**	**5**
Local government	7	21	4	11	0	0	4	17	1	9	**16**	**11**
Public company	2	6	2	5	4	10	1	4	0	0	**9**	**6**
University or state research organisation	7	21	8	22	15	38	1	4	3	27	**34**	**23**
Multisector partnership	1	3	4	11	0	0	7	29	0	0	**12**	**8**
Government Ministry or agency	8	24	11	30	2	5	4	17	1	9	**26**	**18**
Commercial	8	24	8	22	16	41	4	17	5	45	**41**	**28**
Total	**34**	**100**	**37**	**100**	**39**	**100**	**24**	**100**	**11**	**100**	**145**	**100**

The foci of interviewee comments (hydrogen supply, stationary applications or transport applications) give some indication of the degree of salience of each for the interviewees and may in part reflect their differing roles. Most of the comments made on hydrogen supply and use came from Government ministry, Government Agency interviewees and – to a lesser extent - individuals in university or State research institutions. Hydrogen production, including power to gas, was their dominant focus. Fewer interviewees of any affiliation commented on stationary applications of FCH as their core concern, regardless of affiliation. By contrast, transport applications were the main focus of a broad spread of interviewees, with multi-sector partnerships and hydrogen distribution being viewed by many as a part of this. Table 4 shows the split of comments by application in aggregated and Figure 5 by country, with the latter showing a higher salience of hydrogen production for France and Spain, but with Germany being relatively balanced across the three areas of application.

Table 4 Applications of FCHs discussed in the interviews

Technology application	Percentage of comments, all interviewees
Stationary applications	16
Transport applications	44
Hydrogen and non-specified or dual use	40

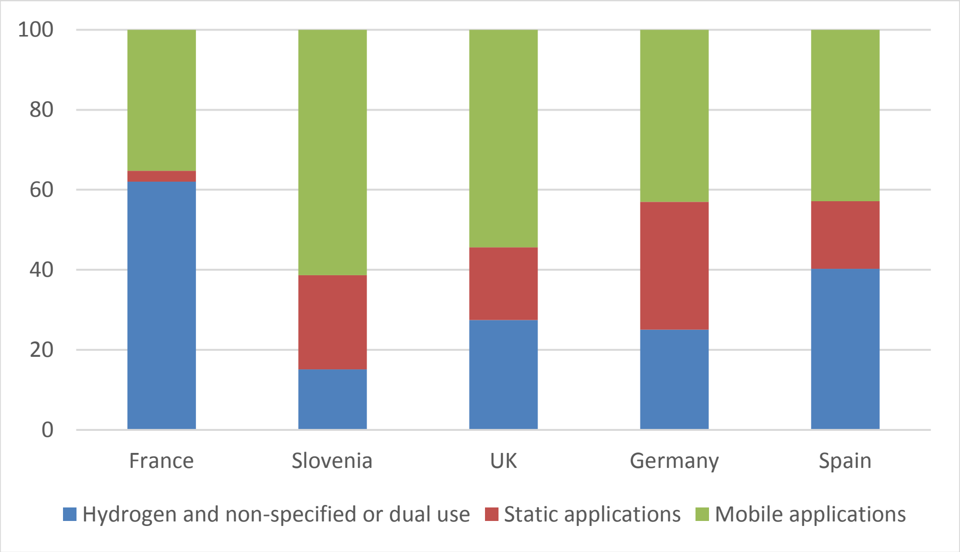

Figure 5 Percentage of comments, by application, by country

2.4 Sample comparison

Two approaches for analysing stakeholders' views were chosen to triangulate findings. The selection for both samples followed different principles. While the survey has the goal of drawing a representative sample, the interviewees were recruited by purpose-oriented approach which started from identifying people associated with exemplary demonstration projects. Thus, differences in sample attributes might be responsible for differences in findings. Therefore it is a relevant question to reflect on in how far the two samples are coherent to each other or whether they include different groups of stakeholders. The latter would imply that results are not comparable. In terms of representativeness and in the absence of information on the views of the total population of stakeholders, the point of reference is the extent to which the characteristics and views of the qualitative sample match those of the quantitative sample. We make this comparison below with the provisos that there is not strict comparability in terms of questions and categorisations and also that some of the interviewees also undertook the survey, such that not all of the stakeholder respondents can function in the role of external validation.

Comparing the nationalities of the survey and interview respondents in percentage terms (see Table 1 and Table 2), showing the main difference as a substantially higher percentage of German respondents in the survey. Regarding organisational affiliations in the survey and interview respondents (see Figure 3 and Figure 2 for the survey and Table 3 for the Interviews): one can see considerable variation between countries in terms of sectoral affiliation, but overall, the main difference between quantitative survey and the interviews is that the private sector formed a larger fraction in the survey for most, but not all countries.

Figure 4 indicates a predominance of background and interest, for the survey respondents, in matters of (a) hydrogen production and fuelling infrastructure and (b) mobile technologies – primary power and drivetrain. This concurs with the focus of interviewee comments, who commented substantially less on stationary applications.

2.5 Methods of data analysis

2.5.1 Methods of quantitative data analysis

The data were analyzed using SPSS software. Initially, descriptive analysis was conducted to estimate the proportion of individuals per country in each of the variables. Comparative analyses with difference tests are provided to study differences between countries and variables. In addition to this, relationships between variables are analysed applying correlational analyses and regression models.

2.5.2 Methods of qualitative data analysis

All interviews were recorded and summarized afterwards. For the interview summaries templates based on the structure of the interview protocol were provided. The interview summaries should provide some background information on the interview: type, date, time and duration of the interviews as well as information on the interviewee. For the actual summary the key points of the interview are to be written down. Important parts of the interview were verbally transcribed and translated in English.

2.5.3 Qualitative coding

This section describes how the qualitative data has been coded with MaxQDA, software intended for the purpose. Coding is a key technique of content analysis, a broad approach used in the social sciences to interpret qualitative data such as interview transcripts. The coding approach used here is both quantitative and qualitative (e.g. Budd, 1967; Weber, 1990; Short et al, 2009). While the majority of the analytic frame and hence codes were pre-determined (i.e. a form of priori coding - Stemler, 2001), in that the frame mirrored the basic structure of the stakeholder survey, the analytic design also allowed for open coding – i.e. for new codes arising from the data to be added (Bernard, 2006; Saldana, 2011). Often, the analyst proceeds through a process of axial coding (identifying relationships between codes) and then selective coding (a further process of condensing codes). Here, the codes being in part pre-determined, thematic inferences are made with the assistance of the MaxQDA 'matrix browser' function, which counts the number of times that text has been allocated to particular codes. Numerical incidence is used as an indicator of relative salience and hence thematic prominence, helping to synthesise the large number of interviews (over 150) to a number of Figures, Tables and illustrative quotations. This is not to say that only prominent themes are reported below – low incidence is also of interest and for some graphics we have separated lower and higher incidence themes to avoid the latter dominating the former. Ulimately there is always analyst judgement involved in coding qualitative material, which is why this process is described in more detail as follows.

2.5.4 Coding specifics

In general, coding consists of selecting text and allocating to one or more themes (in MaxQDA via drag and drop), providing links to the associated text that can be qualitatively and quantitatively represented. If an interviewee mentions an issue twice, separately, it has been coded twice. Quantitatively this gives an indication of the density and salience of issues for the interviewee set as a whole. It also enables the identification of supporting text. It should be noted that in terms of numerical count, coding frequency can be disproportionately influenced by speech and transcription style. This has been borne in mind while drawing inferences: codes such as for country and organisational type can be used to reliably indicate the incidence of interviewee attributes in proportion to the sample population, while the other codes *indicate* the characteristics of the discourse as well as the 'substance' of the total set.

In terms of the coding criteria used, it is neither possible nor desirable to include a code for every comment; moreover all coding is inevitably selective and normative. That is, it involves a judgement regarding what is important and hence worth coding. The main point of coding is to condense extensive qualitative material into themes, such that over-extensive coding is purposeless. Here, priority is given to coding information that provides detail (typically in terms of reasoning and substantiation of views). For example, regarding the perception of relatively high FCH cost, information on which parts of the supply chain have been found to be costly, or that in some cases a surfeit of natural gas is being directed to LPG for cost reasons.

In terms of the choice of the main codes – the categories of *hydrogen production and use*, *stationary applications* and *transport applications* – were determined after consultation with the interviewers and reflects both their overview knowledge of interviewee responses and - in particular - the need to report the results comprehensibly so that readers can use the three main application types as orientation. That is, the threefold separation helps (a) to form main sub-headers for the final report and hence aids comprehensibility; and (b) allows issues to be separated out from within individual interviews even if a particular interview has a particular emphasis. Hydrogen-specific issues are allocated to the hydrogen section but of course will have implications for the other sections. An alternative would have been to organise coding and reporting simply by themes, in recognition of overlaps between the technologies, but this is judged to be of less value to applied audiences.

In terms of additional information on the three categories, here 'stationary' denotes FCHs used to deliver power and heat rather than mobility. As the term ‘mobility’ is here taken to relate to vehicle transport, the stationary category includes portable power such as for a laptop. The

'Hydrogen use and supply' category is used for projects and comments that are primarily about hydrogen production, use and distribution, without a specific reference as regards the use of that hydrogen. It is important to note that this tripartite categorisation is only undertaken as an aid to comprehension. Quite often a project or comment could be assigned to more than one category, but if a project or comments are significantly about vehicles, they are coded as mobile even if they includes some element of hydrogen distribution. Generally H_2 coding is assigned only if the project or comment is centrally about hydrogen production. Note that different comments in one transcript may therefore be allocated to more than one of the three main applications.

Following the above coding process, sub-codes have been further condensed to aid comprehension and graphical representation, by: (a) deleting single-instance codes in long-list contexts (i.e. where only one person has expressed a particular view and there are many views that need to be represented, most of which were expressed by more than one person); and (b) code merger where meaningful. Code merger was undertaken where possible before the deletion option was used. Where necessary, i.e. where a long list of codes remained, lists have been split into high and low incidence groups, again to aid graphical representation. As explained above, while the coding process does entail the loss of some information as conveyed to the reader, there is an unavoidable balance to be struck between overwhelming the reader with too much information and condensing for comprehensibility.

Overall, the purpose of the exercise is to add detail to the surface-level opinion gained via the stakeholder survey. Claims of statistical representativeness relating to a wider population of potential interviewees are made neither for that survey nor for the qualitative coding, though some degree of comparison of the samples and the total population is possible and while also noting that the number of interviews is *substantial* relative to typical qualitative studies. Rather the purpose of the stakeholder survey and interviews is to systematically illustrate and reveal notable issues and opinions held among the target population of actors involved in the FCH innovation system, particularly scientists and engineers.

3 Results from stakeholder survey

3.1 General questions about FCH

The survey for the stakeholder started with a question asking participants about their general evaluation towards FCH-technologies as a possible solution for energy and environmental challenges. Of the participating stakeholders 88 % think that FCH are a good or a very good solution to these challenges. There is some variance in the evaluation across countries, however, these differences do not turn out to be significant.

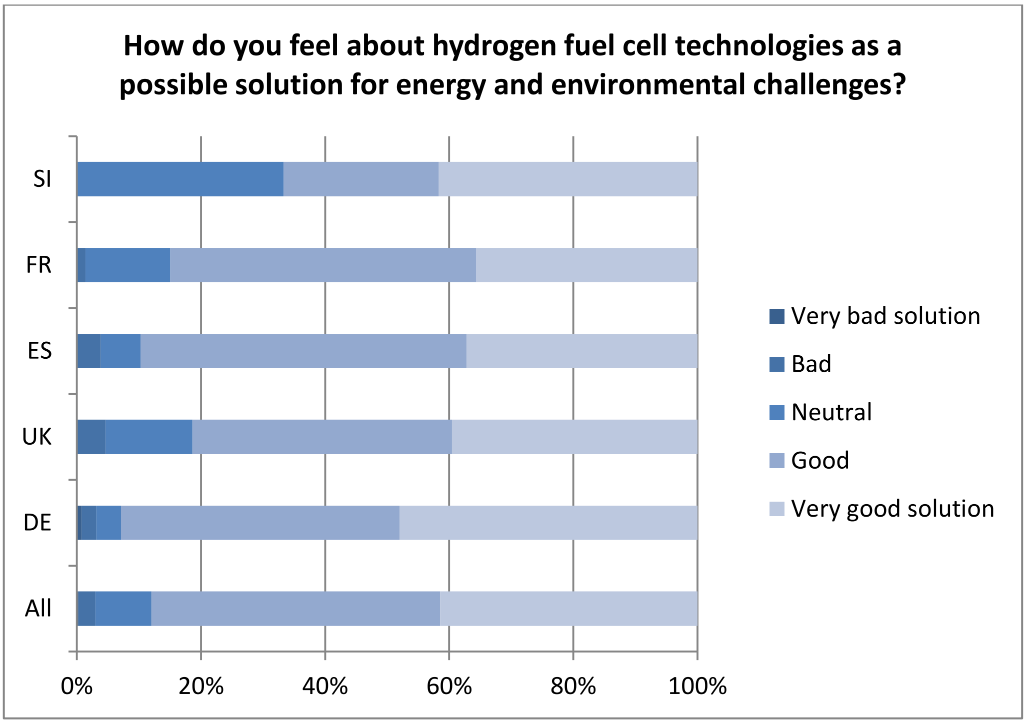

Figure 6 General evaluation of FCH technologies

A further question then asked for evaluations of different FCH technologies.

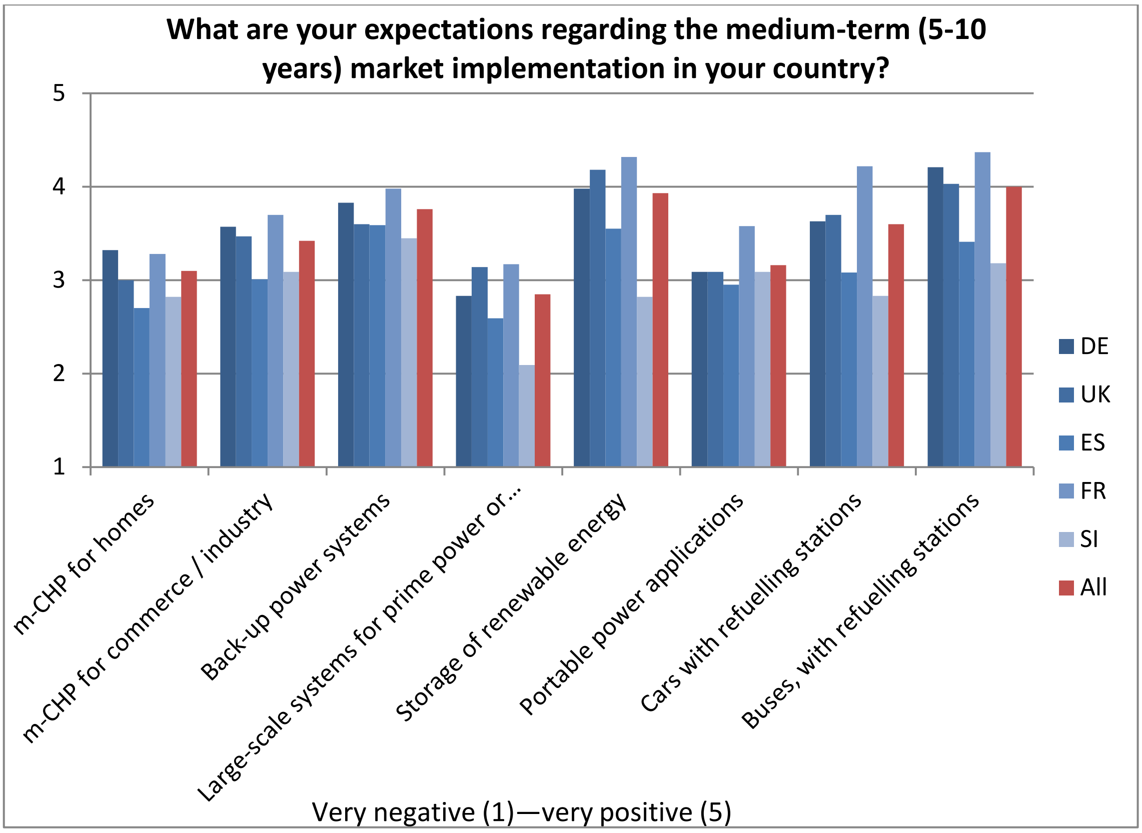

Figure 7 Evaluation of specific FCH technologies.

Table 5 Differences on a country level between stated expectations about market development for several FCH technologies.

	Differences in ANOVA
m-CHP for homes*	DE > ES
m-CHP for commerce / industry*	DE, FR > ES
Back-up power systems	-
Large-scale systems for prime power or CHP*	FR > ES
Storage of renewable energy*	UK, FR> ES DE, UK, FR > SI
Portable power applications*	FR > ES
Cars with refuelling stations*	DE > ES FR > DE, ES, SI
Buses, with refuelling stations*	DE, UK, FR > ES DE, FR > SI
Tested with ANOVAS and post-hoc-tests.	

Across the countries, stakeholders' expectations are more positive for H2-buses and H2 as a means of storage for renewable energy, followed by H2-based back-up power systems. Least positive prospects are seen for large scale systems for prime power. Looking at the results in more detail on a country level, it can be seen that respondents from France are most positive on average, followed by the UK and Germany and Spain and Slovenia ranging behind. Not all, but several of these differences between countries are significant on a technology level (see Table 5).

A further question asked whether the participants from the different countries think that governments should support FCH technologies, only about 5-10 % per country are undecided or do not agree (see Figure 8). Overall participants favour governmental support and differences between countries are not significant.

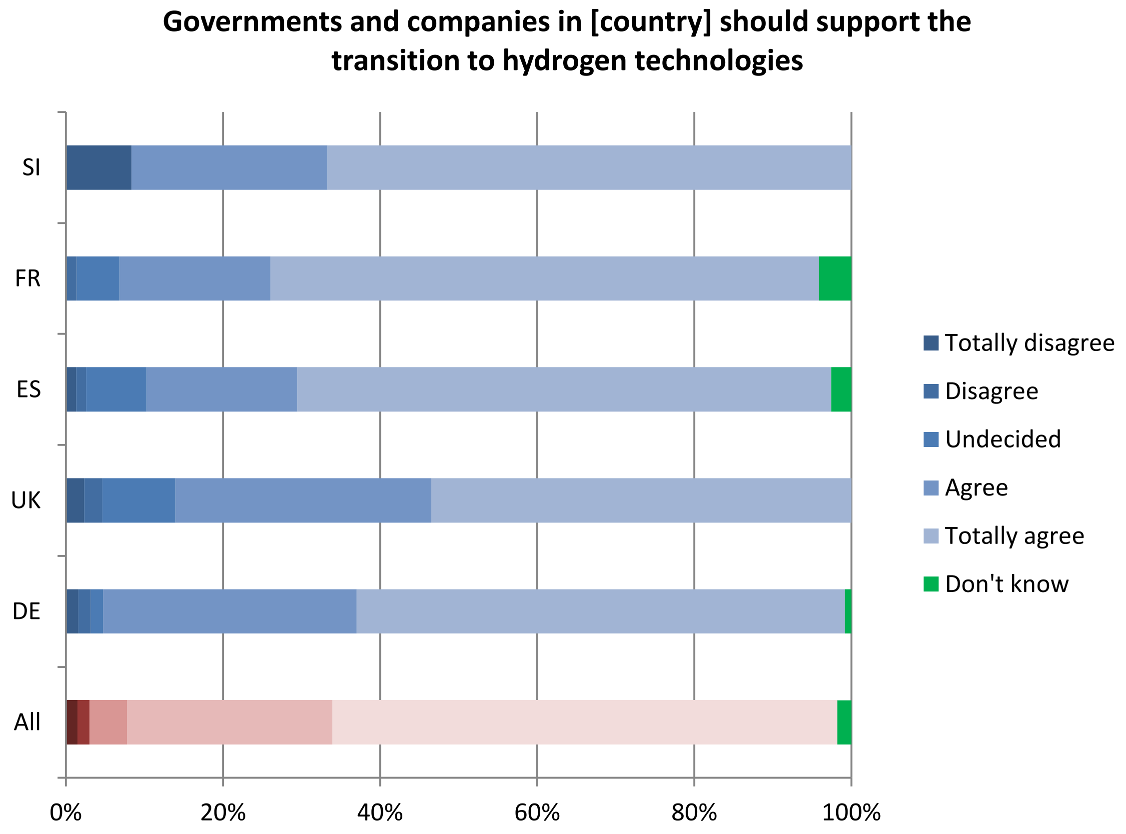

Figure 8 Stakeholder responses to whether governments and companies should support the transition to hydrogen technologies

After those introductory questions participants chose one of two hydrogen applications on which they answered further questions. One of them was FCH stationary applications, the other one H2 powered vehicles. In all countries but Slovenia the majority of participants chose the transport application (see Figure 9), thus, 28 % of respondents answered further questions about the stationary application and 72 % about the mobile one. In the following the results from these questions will be reported.

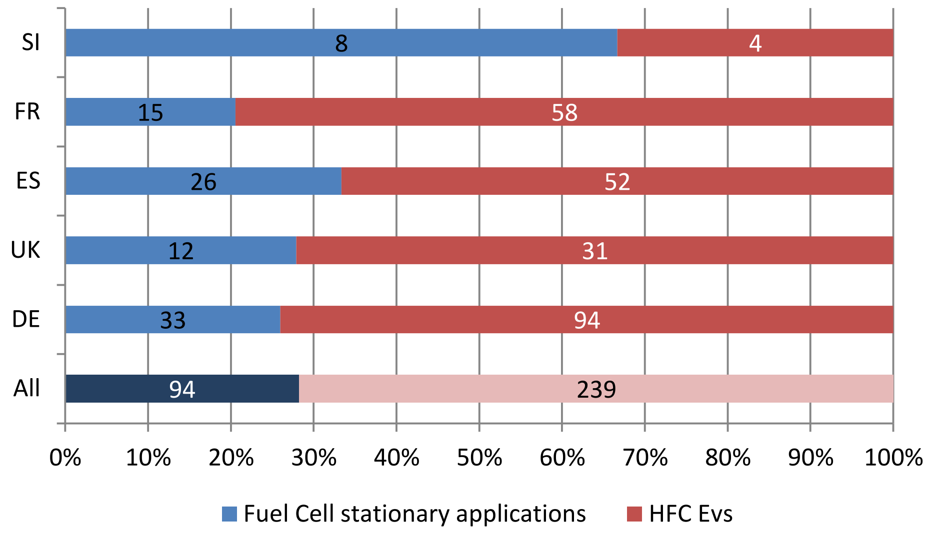

Figure 9 Application chosen by participants

If the choice of FCH application is related to the respective evaluation regarding the medium-term market implementation it turns out that participants rated the application they chose significantly more positive than the one not chosen (tested by ANOVA). This means that on average respondents who answered the questions either about stationary applications or FCEVs hold more positive views on them.

3.2 Fuel cell stationary applications for heating and electricity

This section will present the descriptive finding on FCH stationary applications for commercial and residential use. As from all five countries only 94 participants chose this scenario, country specific data is shown in the graphs, but no tests on significance will be run.

Respondents were asked about their level of familiarity with stationary applications. The answer patterns show that the majority states medium levels of familiarity.

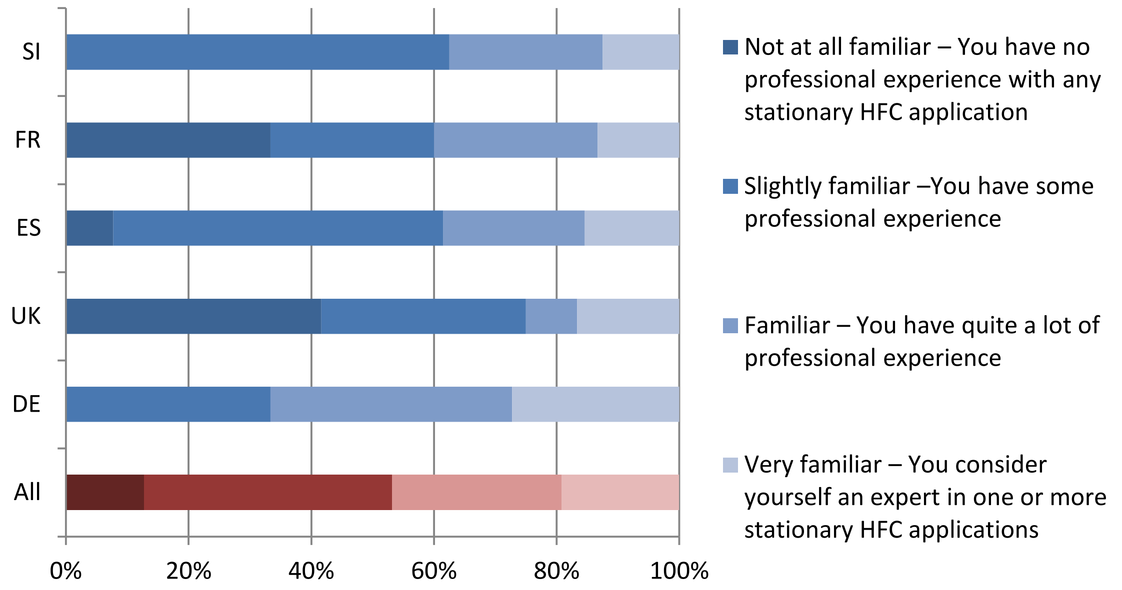

Figure 10 Respondents' familiarity with stationary applications

In a next step participants rated a list of challenges for this application (see Figure 11). Overall, safety is seen as the challenge that is less likely to be serious, cost disadvantages are seen as the major challenge.

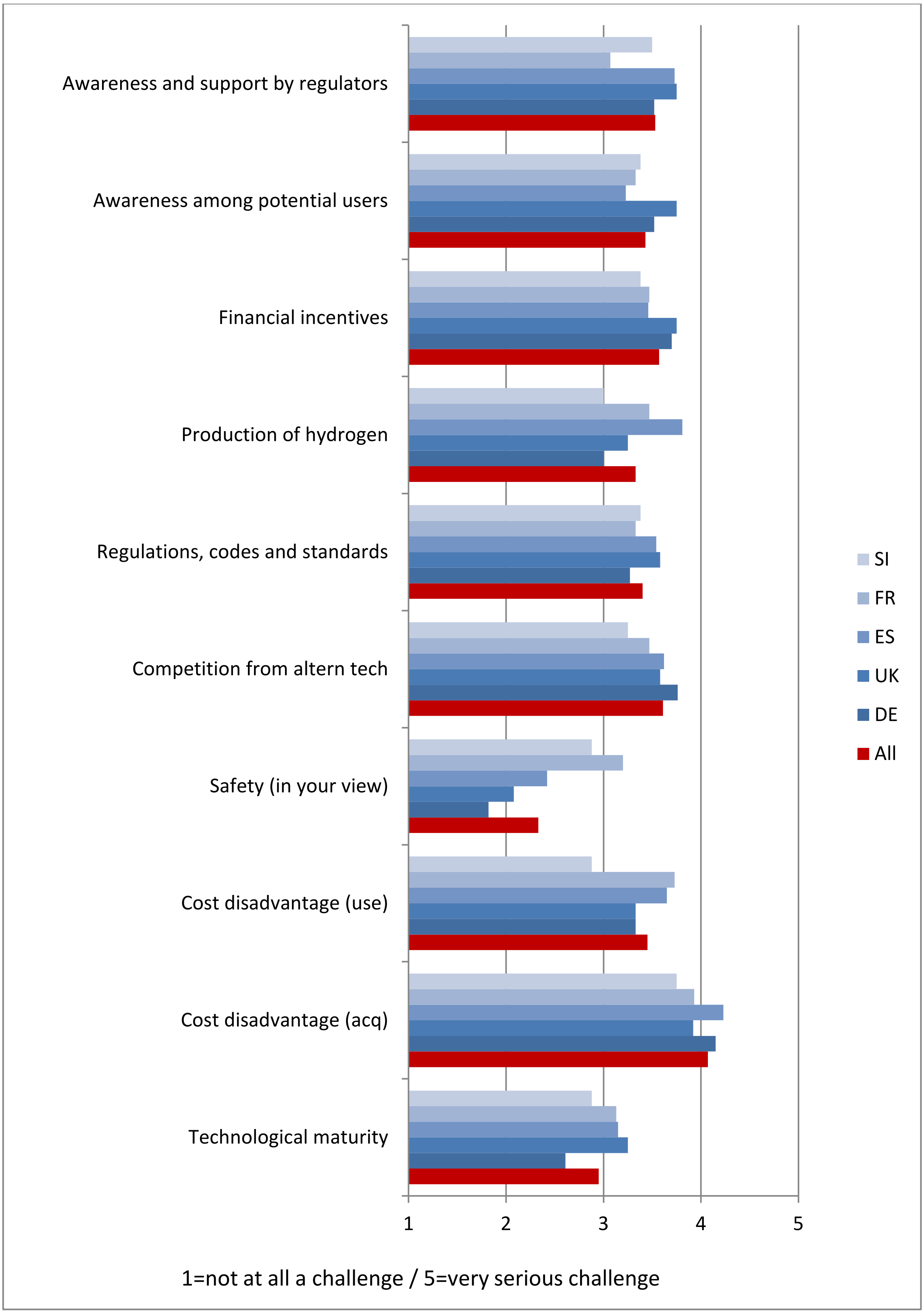

Figure 11 Ratings of challenges to deployment of hydrogen fuel cell stationary applications in respective country.

Participants had also the possibility to mention additional challenges they think will be important. These are sorted into topic and displayed in the following table.

Table 6 Overview over challenges for stationary applications identified by respondents

Topics	**Specific challenges**
Innovation system (technological and environmental issues)	AC/DC conversion; Balance cogeneration; Capabilities of manufacturing sector and supply chain; Economies of scale Increase research grants; Lifetime and degradation; Local generation and accumulation of H2; Reliability of supply; Technological maturity; Use of renewable catalysts
Regulatory issues	National standards for regulation; Network toll; Regulation as a barrier
Public acceptance	Public acceptance; Public awareness; Barriers from users; Hydrogen perceived as risky
Market Development	Warranties and services for systems; Business models for energy storage
Further topics	Cogeneration is questionable; Highly energy efficient buildings; In conflict with (French) centralised energy system based on nuclear; Usage in households

Three further questions tapped on competing technologies to FCEVs. All proposed technologies were seen to be competitive to FCCHP to some extent.

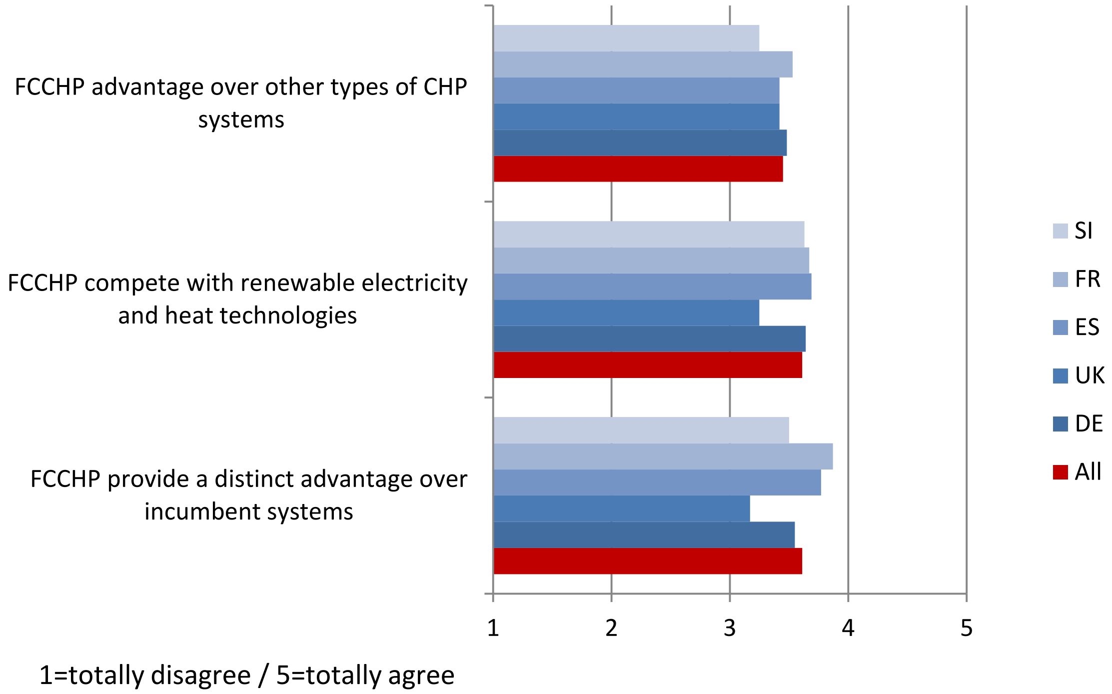

Figure 12 Specific aspects regarding stationary applications

Participants had the possibility to add comments to this question block. The few comments inserted address that dis-/advantages depend on the perspective (environmental, economic, technological), that synergies between technological solutions / fuel cells as a complimentary technology should be taken into account as well and that framework conditions matter. Further they point to the competitive market, the viability of technological issues and environmental advantages.

The next question asked about possible drivers and enablers for stationary applications.

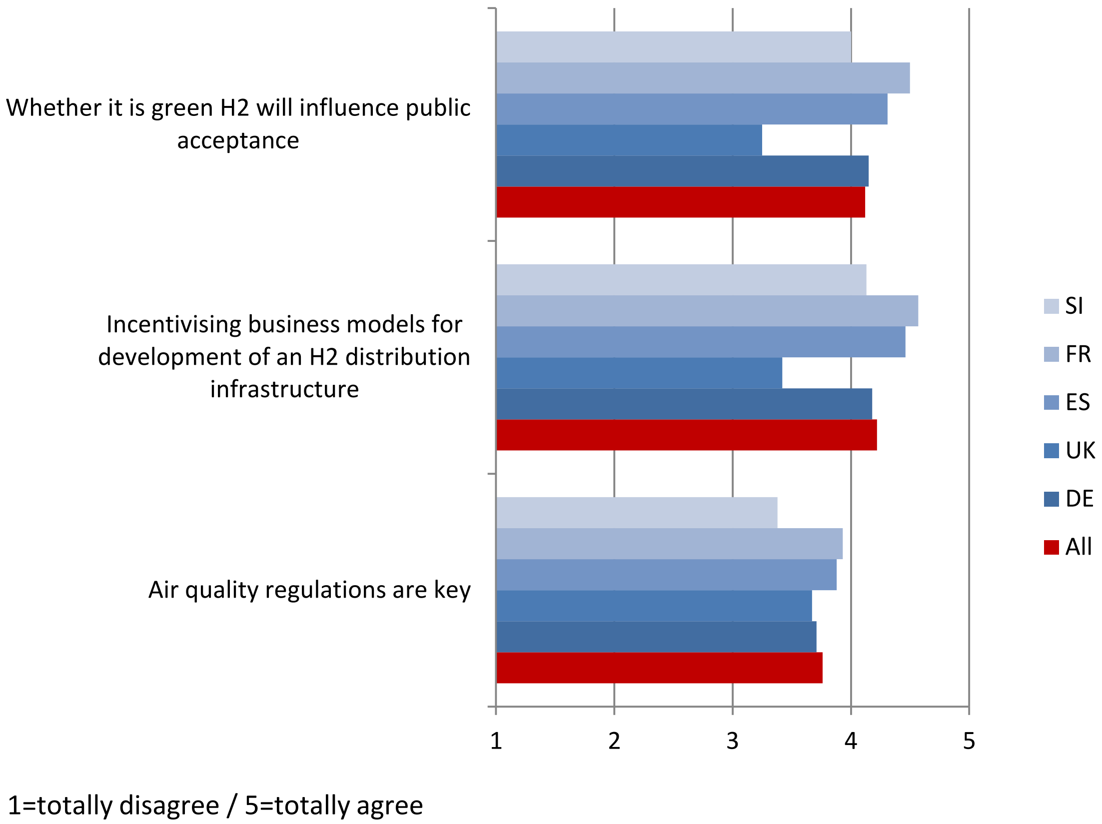

Figure 13 Possible drivers for stationary applications

Additional comments on this part by the respondents refer to cost /price issues, CCS as an alternative approach to deal with carbon emissions, H2-distribution infrastructure as well as general issues around renewable energies.

The next question asked about the use of public funding with regard to stationary applications. Respondents were more positive about funding research and development than the funding for demonstration project and least positive about subsidies on purchase prices (tested with ANOVA for repeated measurement).

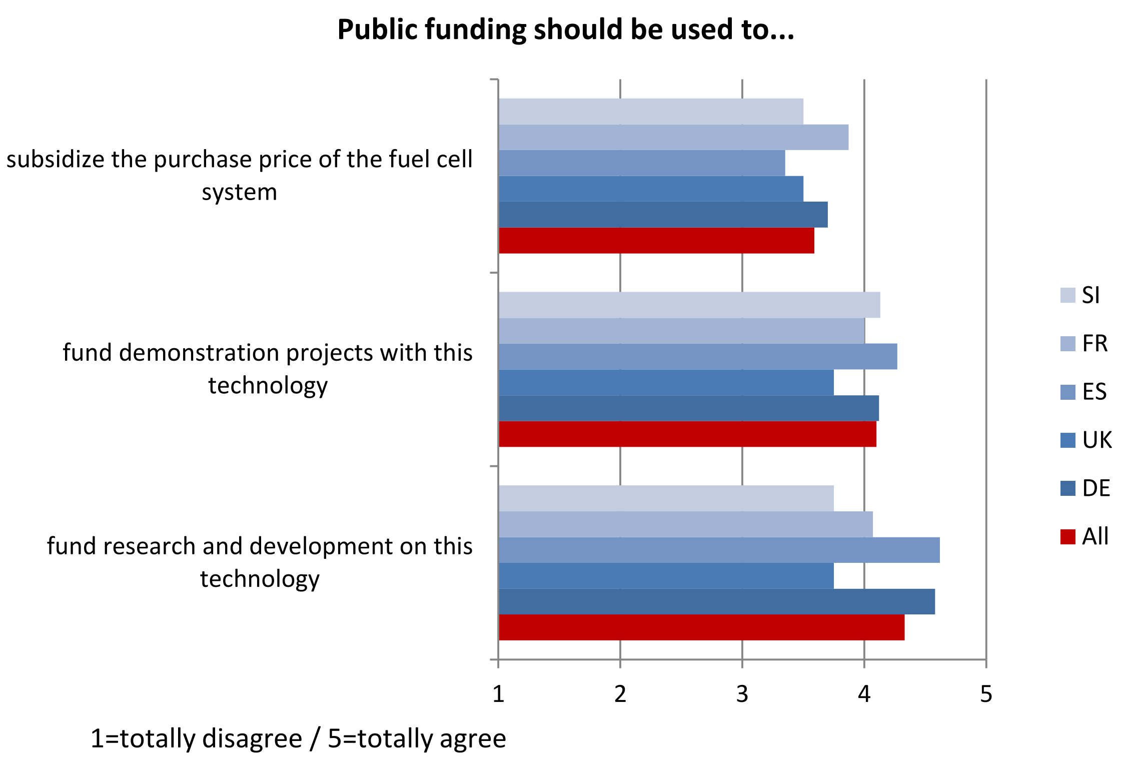

Figure 14 Use of public funding with regard to stationary applications

Participant's further comments acknowledge that subsidies might be important to start the market, however, point out to the challenges inherent in such incentives, e.g. design of programs.

Two further questions asked about the familiarity as well as the attitudes of other societal stakeholders about stationary applications.

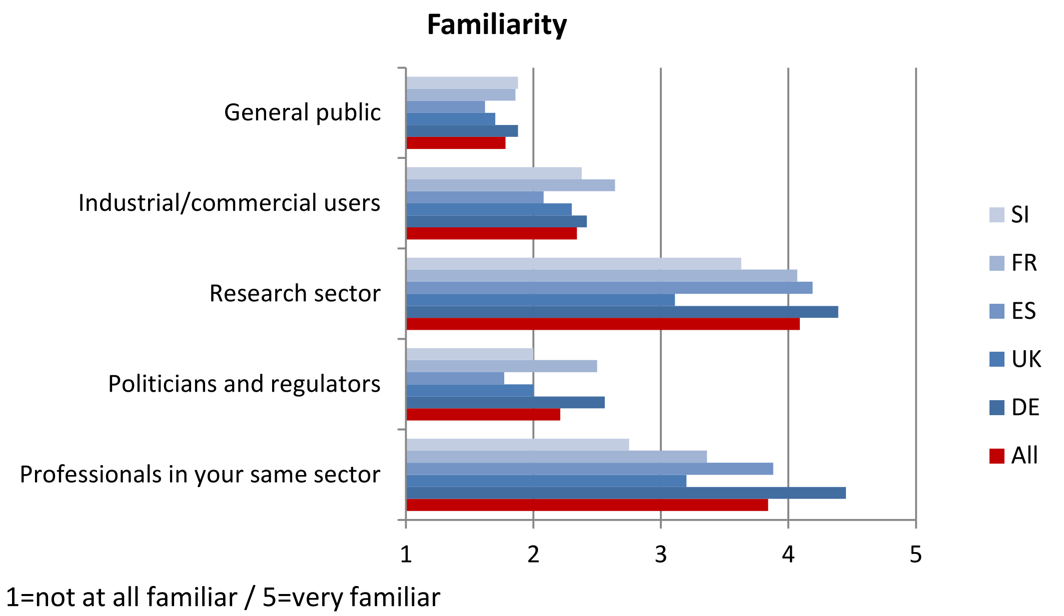

Figure 15 Familiarity of other societal stakeholders with stationary applications

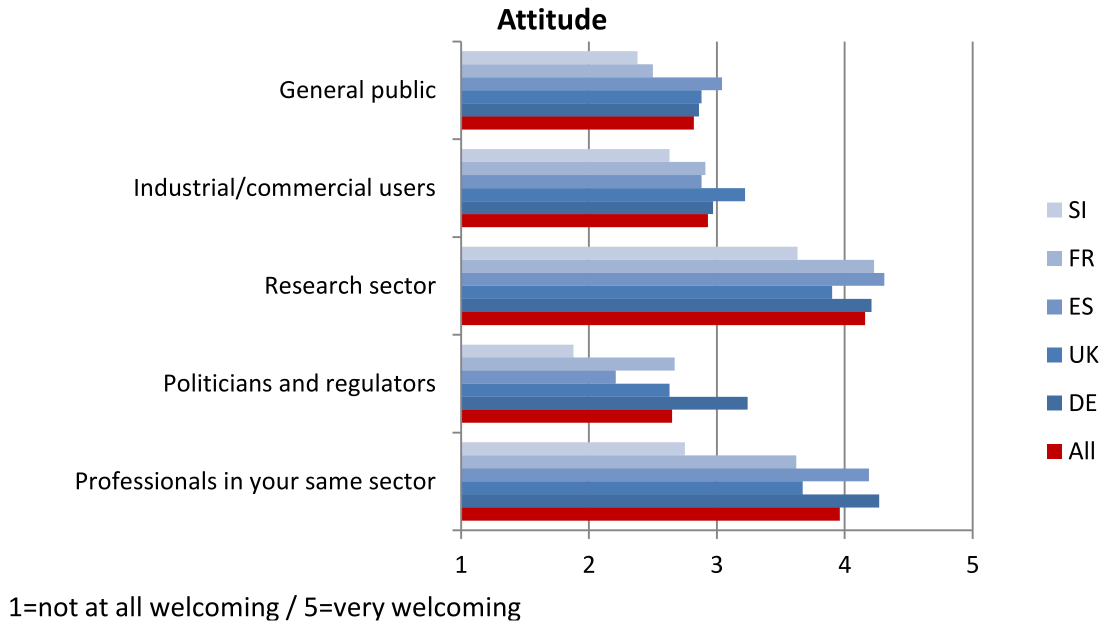

Figure 16 Attitudes of other societal stakeholders towards stationary applications

Familiarity is on different levels for the different groups as rated by the participants. Professionals from the same sector and researchers are rated as having a higher familiarity than all other groups but the research sector. Politicians' and industrial/ commercial users' familiarity is regarded as higher than the one in the public. The public's familiarity is rated lowest, significantly lower than all other groups' (tested with ANOVA for repeated measurements).

Attitudes are also rated differently for the groups under study. The attitude of both the research sector and professionals from same sector is regarded to be higher than the attitude of the other three groups.

Overall, the evaluations of familiarity and attitude are correlated (r between 0.42 and 0.68, p<0.05) on an individual level. However, some of them also differ significantly: The attitude of the general public, industrial and commercial users as well as of politicians is rated higher than their familiarity.

3.3 Fuel cell transport applications and related infrastructures: FCEVs

After respondents chose their preferred application they were asked about their level of familiarity. The answer patterns show that the majority states medium levels of familiarity. Differences between countries are small.[2]

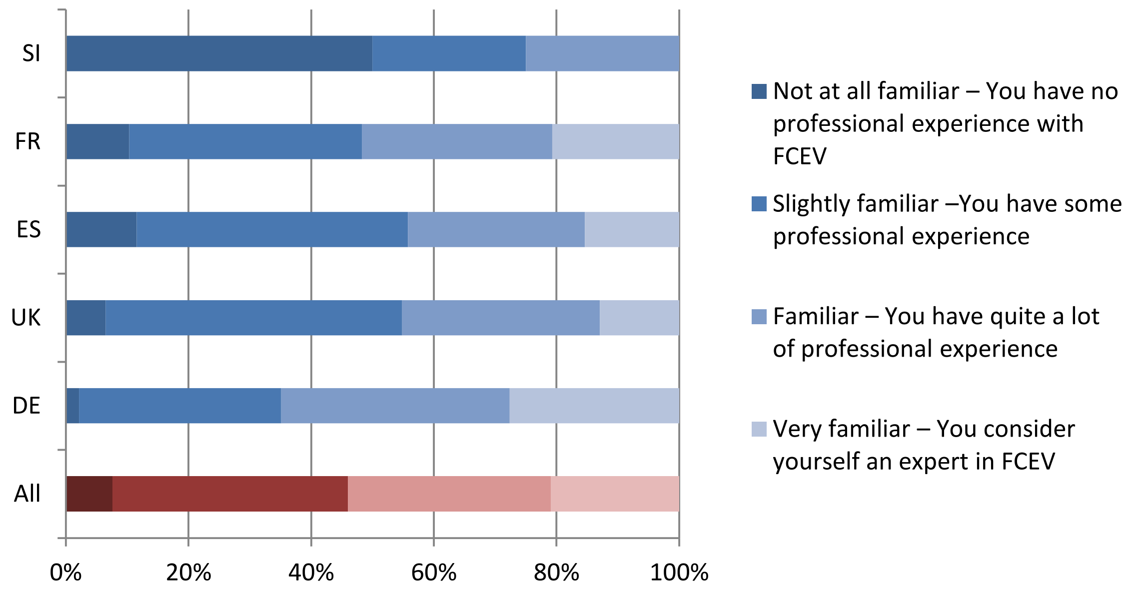

Figure 17 Respondents' familiarity with FCEVs

In a next step participants rated a list of challenges for this application (see Figure 18). Some country differences are detected, most often German participants rated a specific challenge as less serious than one of the other countries. Overall, safety is seen as the challenge that is less likely to be serious, building an infrastructure with sufficient hydrogen refuelling points is seen as the major challenge.

[2] German respondents indicate a significantly higher level of familiarity than Slovenian respondents. No further significant differences.

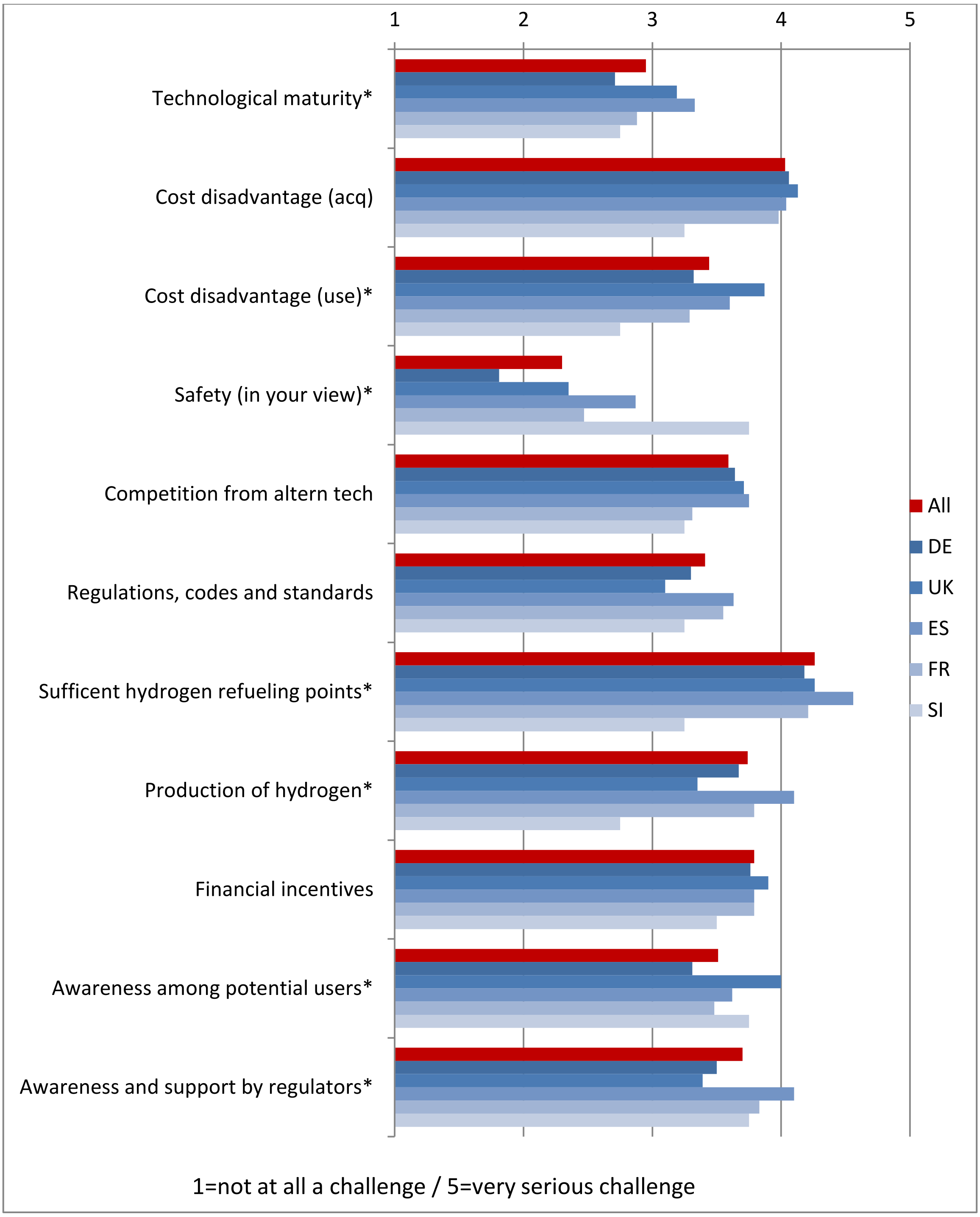

Figure 18 Ratings of challenges to deployment of FCEVs in respective country. *mark challenges with significant differences between countries.

Participants had also the possibility to mention additional challenges they think will be important. These are sorted by topic and displayed in the following table.

Table 7 Overview over challenges for FCEVs identified by respondents

Topics	Specific challenges
Competition	5x Competition with BEVs; Competition with other alternative technologies; International competition
Innovation system (technological and environmental issues)	Creating supply chain; Building stacks >1MW; Challenge of combining transport and H2 market; Cheap electricity production; Durability; 2x Economies of scale; Efficiency of vehicles (consumption/ weight); Environmental advantages for BEVs; Production and distribution of H2; Simplification of solutions; Supply with relevant resources / materials; Unforeseen operational costs; Vehicle range; Velocity too low; Well-to-wheel balance
Resistance from traditional actors	Insufficient activity of German car manufacturers; Implications for French car manufacturers; Level of industrial activity; Lobby of conventional cars; Resistance of actors from conventional fields
Regulatory issues	International standards for recharging modes; Manufacturing of components; More activity and communication; Incentives for green H2; National independence; Independence of fossil fuels; 2x Regulatory Framework
Political will	2x Political reliability; Political stability; Political strategy; Political will
Public acceptance	2x Public awareness; User acceptance; Public awareness regarding future of conventional vehicles; Communication
Market development	Chicken-egg problem; 2x Diffusion; Vehicle models available
Further topics	2x Reliability of refueling stations; Use for great distance transport (trains)

Two further questions tapped on specific issues related to FCEVs. In the infrastructure question the ratings from Germany differ significantly from those in France and Spain.

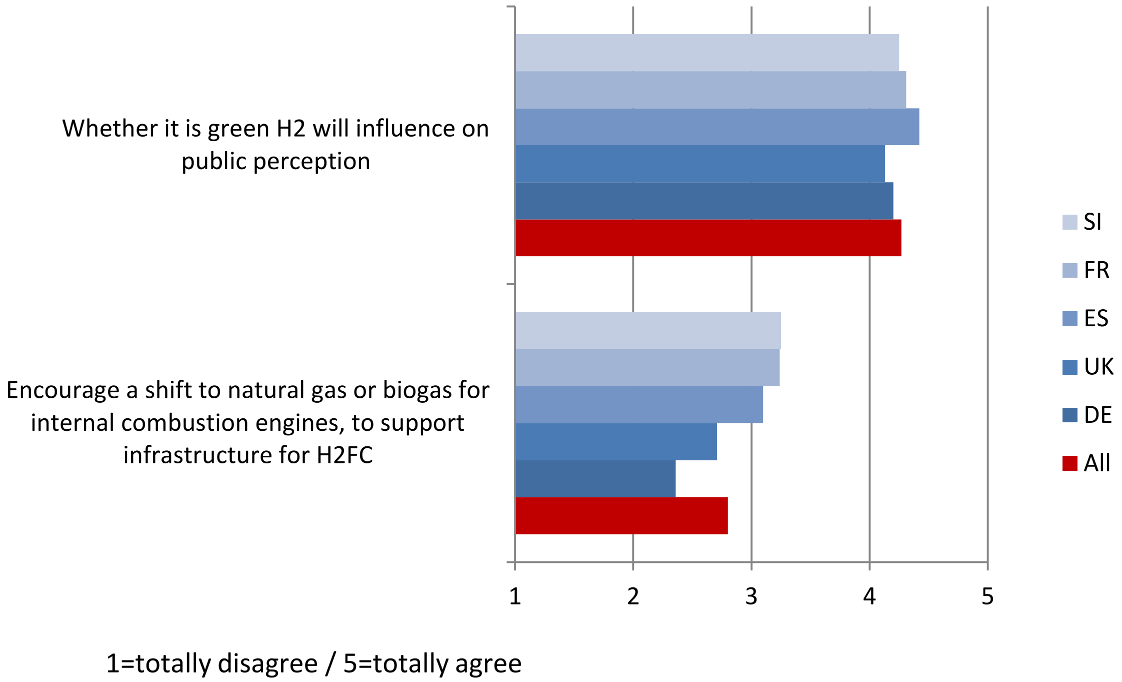

Figure 19 Specific aspects regarding FCEVs

Participants had the possibility to leave comments on this question. The comments inserted refer to the role of hydrogen in an increasingly renewable energy system, its relationship towards conventional fuels and other alternative fuels (co-existence, replacement, support), around green hydrogen, not limiting hydrogen to fuel cell applications, no local emissions, a conflict of interest with oil producing countries, to the impression that France is behind in battery development and the need to implement hydrogen in national strategies.

The next question asked for a comparison with other propulsion technologies and fuels. On average participants favour FCEVs over all other technologies listed. However, the highest advantage is ascribed in comparison to conventionally powered vehicles and is smallest in comparison with BEVs. Country differences are small and significant only include lower ratings in Slovenia compared to some of the other countries.

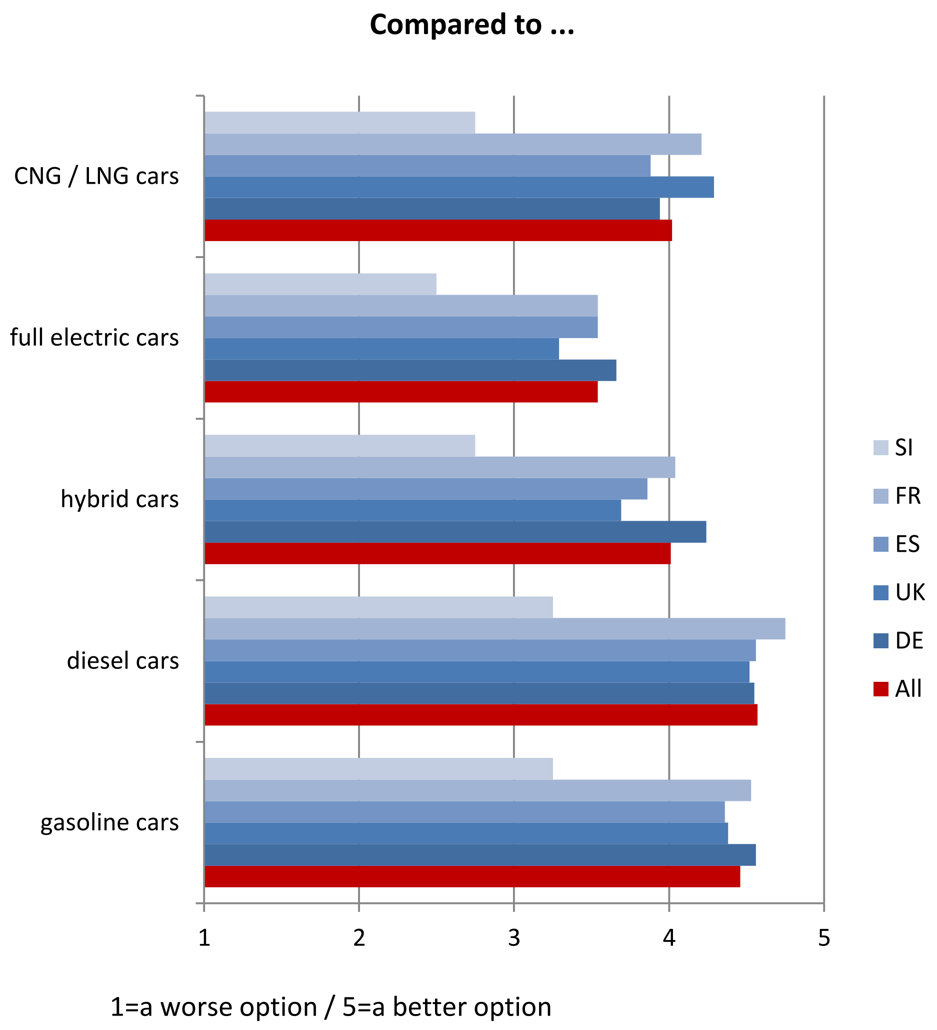

Figure 20 Comparison between FCEVs and other fuel types

From the participants who used the comment function to this question several stated that they found it difficult to compare different powertrains / fuels as the result depends on the perspective taken. In addition to this, some more pointed out that advantages depend on the use case and / or that BEVs and FCEVs are suited for different mobility patterns. Further comments include statements like clear advantages for FCEVs; costs as key factor; environmental advantages of FCEVs, but weak on refueling infrastructure and costs; evaluation depends on how hydrogen is produced; FCEVs have zero emissions; hydrogen as a solution for transport and heating; if battery range increases BEVs are advantageous; only BEVs and FCEVs are technologies for the future.

The next question asked about the use of public funding with regard to FCEVs. Again, country differences were small. However, respondents rated the installation of hydrogen refuelling points as a top priority along with funding research and development and considering demonstration projects significantly less important and subsidies for the purchase of FCV-EVs even less relevant (tested by ANOVA for repeated measurement).

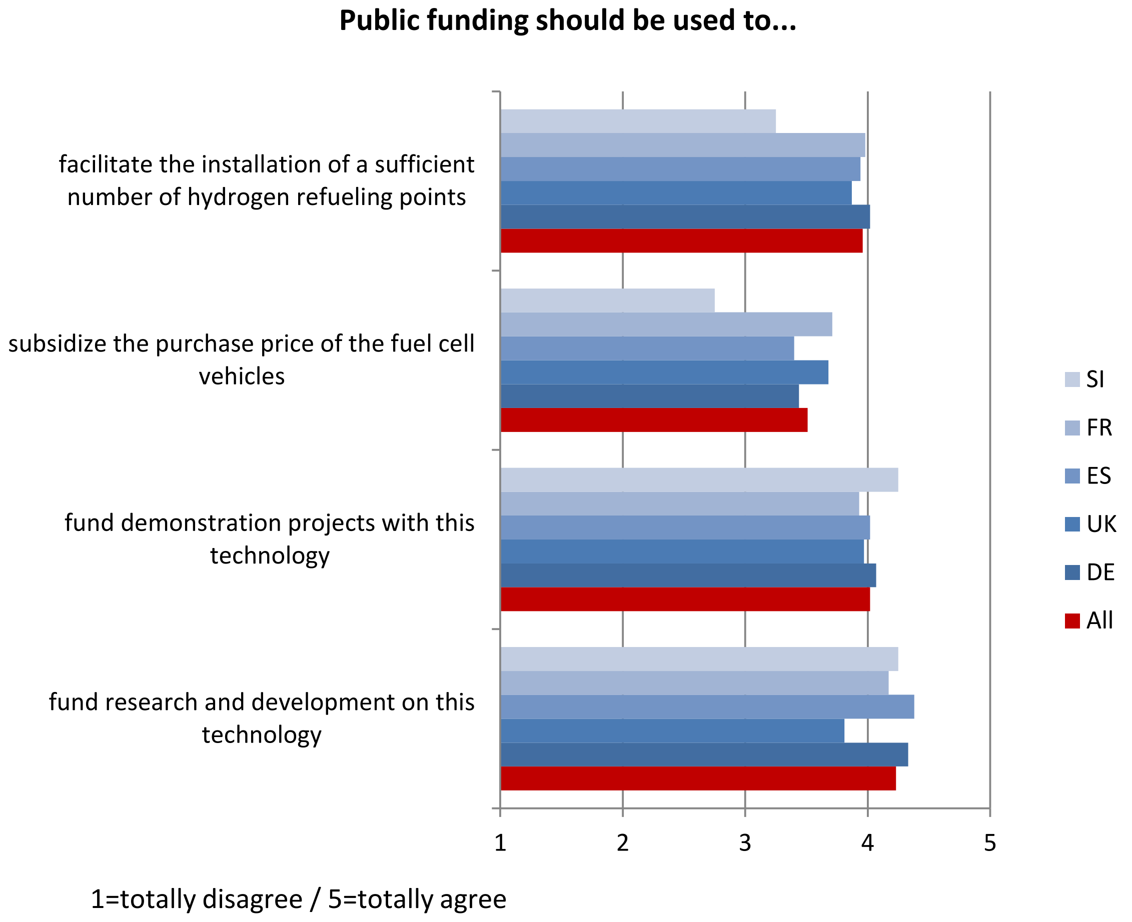

Figure 21 Use of public funding with regard to FCEVs

Some comments were also left reacting to this question. However, they point to a heterogeneity of views across stakeholders whether demonstration projects or financial incentives are useful at all, for FCEVs or in this stage and how they should be designed. They also point out that acceptance from stakeholders, especially those favouring conventional technologies, is more important, that we are talking about globally emerging markets and also referred back to the issue of green hydrogen.

Two further questions asked about the familiarity as well as the attitudes of other societal stakeholders about FCEVs.

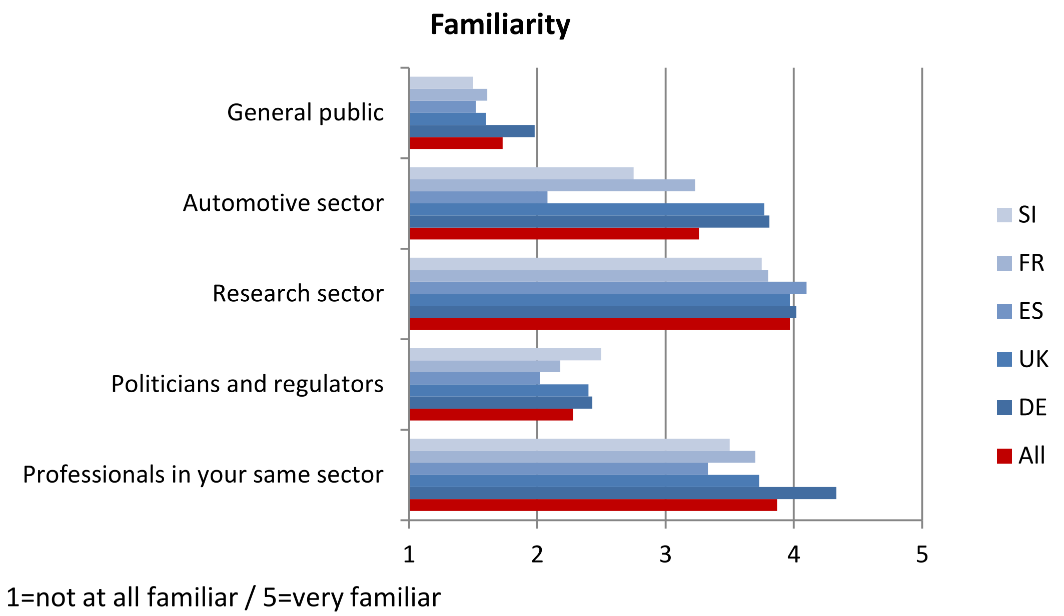

Figure 22 Familiarity of other societal stakeholders with FCEVs

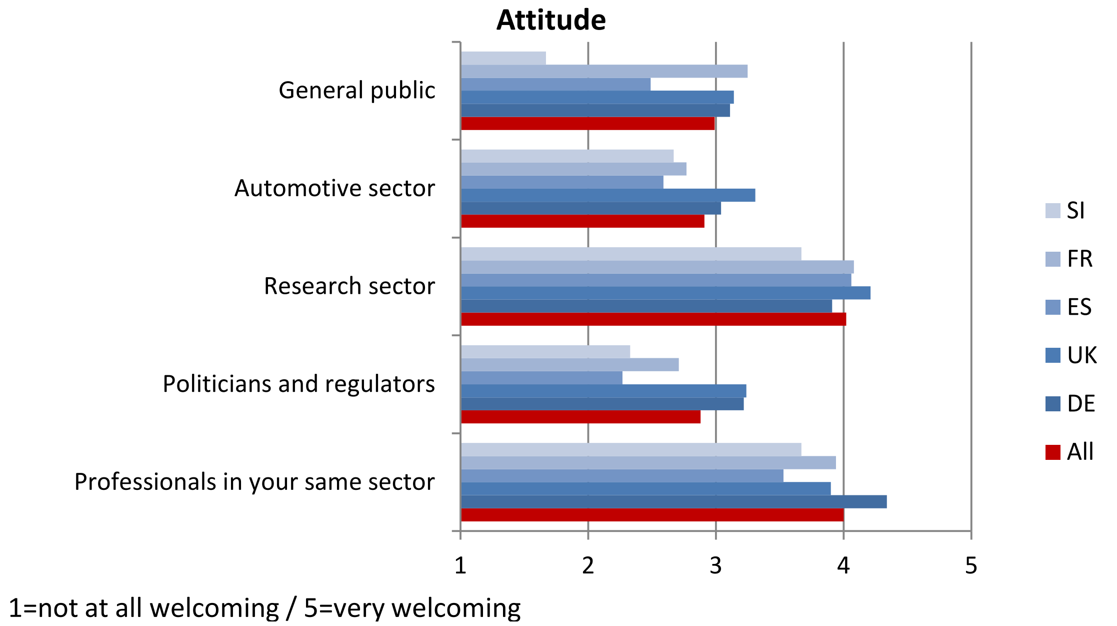

Figure 23 Attitudes of other societal stakeholders towards FCEVs

Familiarity is on different levels between the different groups as rated by the participants and all of them differ significantly from each other with one exception, research sector and professionals from same sectors are rated on the same level (tested with ANOVA for repeated measurements). These two groups are also rated to be those with the highest level of familiarity while the lowest level of familiarity is ascribed to the public.

Attitudes are also rated differently for the groups under study. Similarly, no difference in attitudes is seen between research sector and professionals from same sector. Politicians and regulators are seen to be on the same level with general public and the automotive sector.

Overall the evaluations of familiarity and attitude are correlated (r between 0.26 and 0.64, $p<0.05$) on an individual level. However, some of them also differ significantly: The attitude of the general public and of politicians is rated higher than their familiarity while the reverse applies for the automotive industry.

Some country differences also emerge: Familiarity is rated higher in Germany for the general public, the automotive sector and professionals in the same sector than in Spain and France. Additionally, for the automotive sector, familiarity in Spain is rated lower than in the United Kingdom and in France. Attitudes in Germany are rated higher than in Spain for the general public, the political sector and professionals from the same sector. For the United Kingdom the automotive sector and the political sector are also rated higher than in Spain. And finally the attitudes in the German political sectors are perceived to be more positive than in France (all tested via ANOVA and post-hoc tests).

3.4 Factors influencing market development perceptions

To identify which factors are related to the expectations regarding the medium-term market implementation of stationary applications and of FCHEV multivariate linear regression models were run. Regarding the evaluations of stationary applications the average of two items (i.e. "small systems for micro combined heat and power (m-CHP) for home operations" and "small systems for micro combined heat and power (m-CHP) for commercial and industrial operations") was used as the dependent variable. For FCEVs the evaluation of the medium-term market implementation for such vehicles served as the dependent variable.

The following blocks of questions from the survey were identified as possible predictors (see Annex for full questionnaire):

- Question 11: Challenges for deployment
- Question 13 stationary / 12 mobile: Enablers / specific issues
- Question 12 stationary / 13 mobile: Comparison with competing technologies
- Question 15: Familiarity of other groups of actors with [X]
- Question 16: Attitudes of other groups of actors for [X]

Although recommendations from the relevant literature on recommended sample size are ambiguous, the number of respondents especially for stationary applications is relatively low to run multivariate analyses. This is enhanced by the fact that (i) it is not clear whether the sample is representative (ii) the sample contains homogeneous subgroups, i.e. respondents from different countries and organizational backgrounds. Therefore not all potential predictors were included in a regression model at once, but a stepwise approach was taken. The items from each question block were added separately to a regression equation. Those items that turned out to be significant ($p>.1$) were then added to the final equation for each application. The results of this analysis are presented in the following table.

Table 8 Multivariate regression on evaluation of medium term market development

Question block	Stationary applications		FCEV	
Challenges for deployment		n.s.	Competition from alternative technologies	-.198*
			Access to financial incentives	.032
Enablers / specific issues	Air quality regulations	.199*		n.s
	Business models for H2 distribution infrastructure	.280*		
	Fuel used for H2 supply	-.187		
FCH can compete with	Renewable electricity and heat technologies	.458**	Full electric cars	.158*.
			CNG / LNG cars	.163*
Actor familiarity		n.s.	Professionals from same sector	-.039
Actor attitude		n.s.	Professionals from same sector	.211*
			Automotive sector	.171*
			General public	.066
R		.636**		.523**
Corr. R^2		.376		.244

Note. Cells give standardised regression coefficients if not indicated otherwise. ** - p<.01; * - p<.05

For both, stationary applications and FCEVs, two highly significant models are identified that explain a relevant amount of variance (38 % and 24 % respectively) respectively containing four and eight predictors.

With regard to stationary applications, the strongest predictor for the expected market development for FCH-systems is in how far a respondent thinks that FCH technologies are able to compete with renewable electricity and heat technologies. In addition to this, significant relationships are also identified for air quality regulations and the development of business models for H2 distribution infrastructure, i.e. participants who think that air quality regulations along with the development of business models will support the deployment of FCH technologies are also more positive about the expected market development for FCH systems.

For transport applications, we find five significant predictors, none of them clearly emerging as the most important one. Competition from alternative technologies is seen as a factor that might hinder market deployment. It is thought to be more likely by people who are under the impressing that FCEVs are able to compete with full electric cars as well as CNG / LNG cars. Furthermore, the attitudes of professionals from the same sector as well as from the automotive sector are identified as significant predictors, i.e. those who think that these actors are more positive about FCEVs are also more optimistic about future market development.

4 Results from stakeholder interviews

In the next sections the findings from the stakeholder interviews will be presented. This chapter is organised into three sections following the main application categories identified, i.e. hydrogen supply and use, stationary applications and transport applications. For those three further subsections refer to perceived strengths and weaknesses, expectations and finally recommendations for each. The main approach for presenting the findings is through graphical summaries and accompanying comment and illustrative quotations. It may be noted that the quotation sub-headers do not map directly to the column axis descriptors in the figures. There are a number of reasons for this. Firstly, bearing in mind that the main point of coding and thematic analysis is to systematically reduce the volume of original material while abstracting the core meanings of texts, the selection of quotations is made on the basis of added value in terms of providing sufficient additional and nuanced information to merit inclusion. This introduces an element of partiality: not all column descriptors are allocated a quotation. There is not space in the report to be fully inclusive. Second, the quotation sub-headers have been chosen to represent the meaning of the quotation(s) that follow, whereas the column descriptors are more general, needing to represent many, varied items of text. For both reasons, direct mapping is not possible.

4.1 Hydrogen supply and use

In this section we present the themes evident in the interviews through graphical summaries and accompanying comment and illustrative quotations, with figures presenting counts (the number of times that themes are referred to by interviewees). Again, results are presented according to the three main categories of hydrogen supply, stationary applications and transport applications to allow for separate reading, with some repetition of issues raised. Overall, to reiterate, the key criterion used for results selection is to provide information either that is considered to be either generally beyond common knowledge – for which purpose the commentary and quotations need to be read - and to indicate the degree of salience of particular issues, the latter through the graphs.

The Figures use numerical counts rather than percentages by country or category, as this allows the reader to draw their own conclusions more reliably: the overall distribution of responses on a per country basis across categories is evident at the same time as information on the differing numbers of interviewees per country. Illustrative quotations add qualitative detail, have been drawn from a total of approximately 500 quotations and are selected on the basis of being judged to add nuance or substance to issues that are in general relatively well known. While we use counts to help summarise the large quantity of qualitative data and to indicate group salience, it bears iteration that this is primarily a qualitative study; all individual views expressed are considered valuable. As interviews were conducted on the condition of anonymity, we cannot identify individuals or organisations and restrict source attribution to only the simplest forms of sectoral affiliation. Comments in sequences are by different interviewees unless quotation marks are left open across paragraphs. The number of quotations per country in part reflects the extent to which interviewees were forthcoming in their responses, this being an additional reason for the use of quantification of thematic incidence as an indicator of theme salience (i.e. the Figures and the quotations should be considered in the light of each other and also in the light of the differing number of responses across countries).

4.1.1 Hydrogen supply and use: perceived strengths

This section summarises references to the strengths of hydrogen supply and use primarily as a central focus. The environmental performance of hydrogen is seen as a key strength (Figure 24). In addition, another dominant strength of hydrogen is perceived as its versatility, specifically its utility as an energy storage vector for renewable energy supply, both per se and in relation to electrical grid balancing.

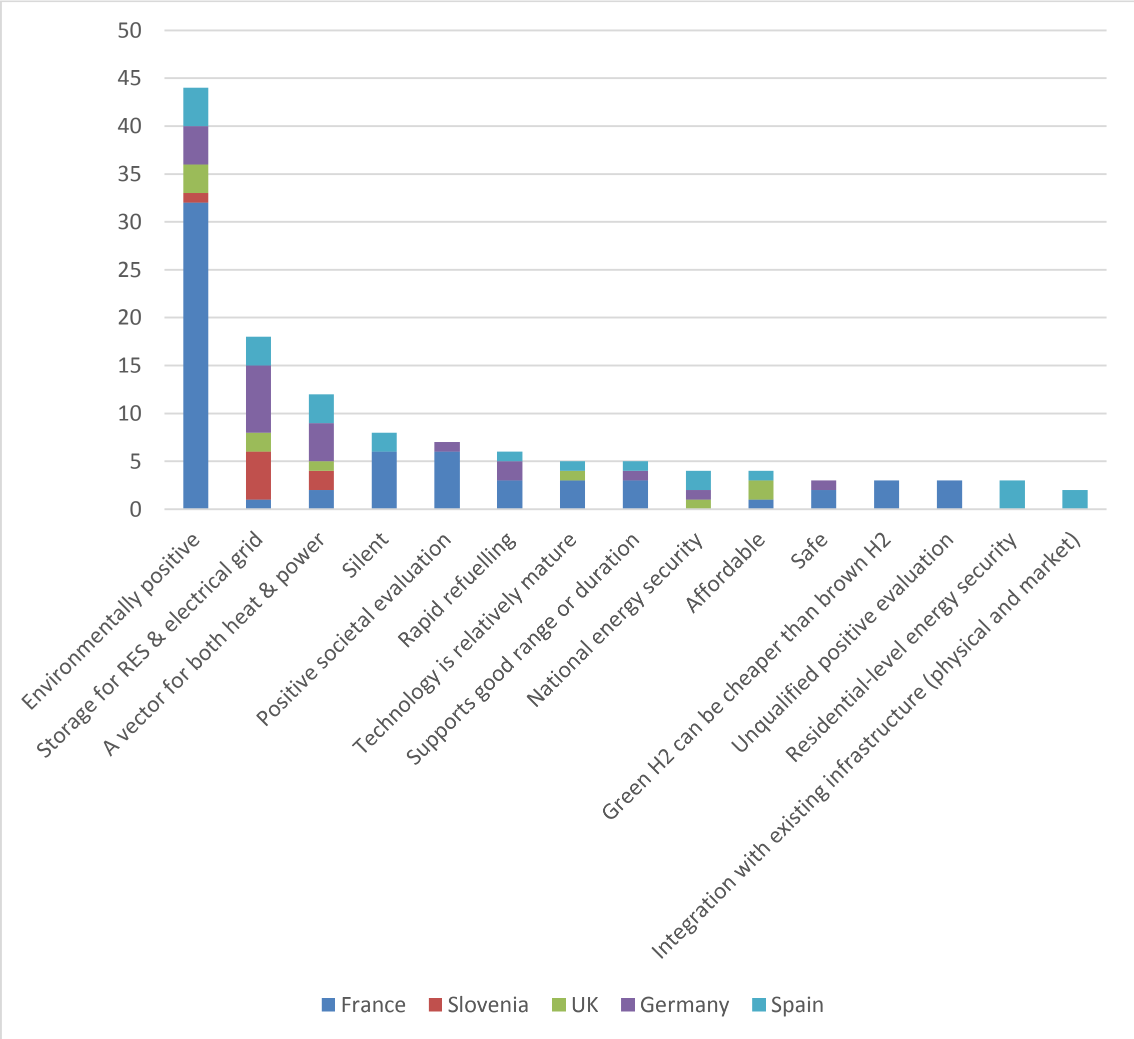

Figure 24 Hydrogen supply and use: perceived strengths

In more detail:

Dimension	*Quotes from stakeholders*
No harmful local emissions	"It offers a superior performance since while maintaining the same benefits of conventional fuel cars, it does not produce any noise or pollution." *France, public sector.*
Less dependent on scarce metals than batteries	"Lithium batteries are obviously an alternative, and they have been making incredible progress, in the last ten years. But the problem we have is that lithium is a scarce metal on earth. And there may be problems, the cost of lithium can grow, and in fact the battery itself is quite expensive. It is the problem of electric cars; the batteries. So again if the price of the batteries goes up and are very expensive and the fuel cell is cheaper, then the fuel cell electric car will win. If we have cheaper fuel cells, without platinum, then we will begin to enter the market." *Spain, public research centre.*
Storage	"The key difference between fuel cell and battery is to do with how hydrogen can be used to store energy in a cost-effective way and especially in mid to large scale applications. It would not be affordable using battery storage systems. A key advantage of hydrogen and fuel cell is down to energy storage capabilities and the cost-effectiveness of this." *UK, public sector*
Versatility	"The generation of hydrogen makes a lot of sense, because it is a fuel. The generation of a fuel in a distributed manner works for all the applications you can think of. You put a solar panel on a site, a small hydrogen generator and you are producing fuel. What do you use it for? For everything you want. For burning it… There are many uses. It serves you as gasoline." *Spain, private sector.* "We could've gone electric, that makes sense, but that's a problem on the islands. An electric-diesel ferry is no good because we would have to change our ferries. We are using electricity, but cannot guarantee it's fully green. Could we have looked at LNG and LPG? No, because we have to bunker it and that's expensive....". *UK, public sector.* "Hydrogen provides a great range of applications compared to other technologies: storage, reconversion into electricity, usage for mobility, industry, different sectors." *Germany, private sector.*
Uninterruptible power	"Also for generators in isolated cases, or where you need security of supply. This is interesting on many levels. For example, a hospital cannot remain without electricity. Neither computer companies and data centers. Here the competitor would be the diesel generator... If you connect it to the gas network, which is a super robust network, that would be a competitive advantage because you are not limited to your tank. And then in terms of efficiency there are huge differences. A motor can achieve a 25% of efficiency, a fuel cell can reach a 60%, demonstrated. Therefore, you are doubling the

	efficiency. Therefore, is economically profitable as long as you recover the purchase cost, given that the investment is much higher. Especially now that it is not manufactured on a large scale." *Spain, public research centre.*
Safety	"...hydrogen is more "secure": a gas car catches fire, a gasoline car explodes." *France, private sector.*
Equitable	"The main opportunities lie in addressing fuel poverty. Grid constrained turbines could produce hydrogen from energy." *UK, NGO*
Positivity	"The more we've spoken to people the more that they have been positive that this the real answer. When you say let's start pumping hydrogen into people homes rather than natural gas there is immediate we don't want to do that that's dangerous isn't it? Then you point out that up until 1970 we were pumping hydrogen into people's homes and mixing it with poisonous gases like carbon monoxide. " *UK public sector* "I think what we've seen of the last 3 years is a move from total scepticism to an expectance that is an option that we need to look seriously at. " *UK, public sector*
Portable power	"The advantages looked fantastic. Having autonomy for a camping vehicle is wonderfull. You are able to park on the mountain and stay up to a week without having recharge it. Then there was great acceptance because it really did not change any of your habits. You had the advantage of autonomy for a week." *Spain, public sector research* "For portable applications, lithium battery has no rival. The problem is that the functionality of the application improves (following Moore's Law) and lithium batteries cannot follow this trend. Sooner or later this will be a problem ... Here hydrogen fuel cells could play a role." *Spain, public sector research*
Reliable	"The machine (FCH) is very stable, very reliable; the reliability of the technology is very high." *Spain, private sector*

4.1.2 Hydrogen supply and use: perceived weaknesses

The key perceived weakness of hydrogen is overwhelmingly seen as its cost, followed by inadequate or excessive regulation and lack of markets or market acceptance (Figure 25). A long list of various further issues is brought forward as well.

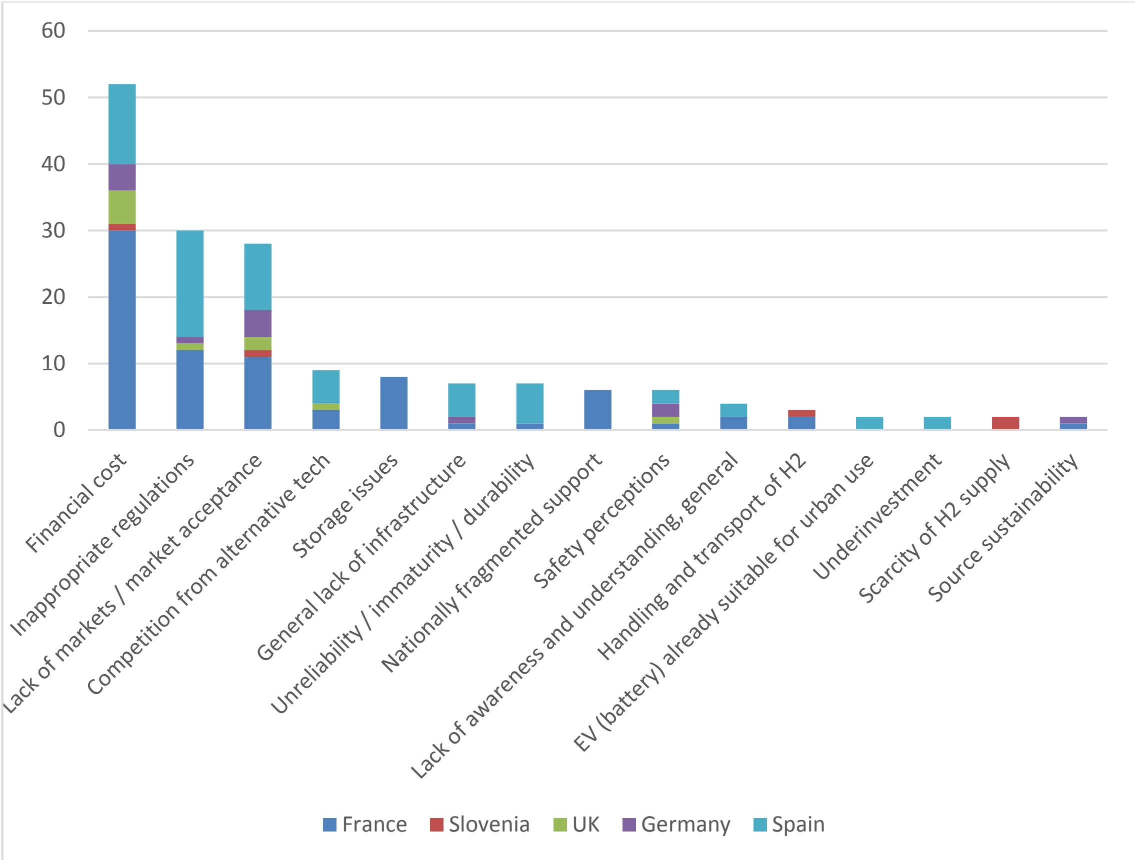

Figure 25 Hydrogen supply and use: perceived weaknesses

In more detail:

Dimension	Quotes from the stakeholders
Cost	"The main challenge for us is to produce hydrogen at a competitive price, which today only happens with natural gas." *Spain, private sector* "Hydrogen production (it is needed a very pure hydrogen – 99.9999% pure – and it is extremely expensive to produce." *Spain, public sector*
Regulation	"Another problem is that there is no legislation. We had an experience in 2008 with a wind power company. We wanted to install a demonstration facility and we collided with the legislative barrier. You go to the corresponding council and the council looks away. The city council, the regional department or the ministry do not even know where to fit a project of these characteristics, because there is no legislative basis about these technologies ... it happens in all the applications of hydrogen. Try to convince the municipal administration or the municipal technical services to install a hydrogen refueling station in the center of a city. Very difficult."

	Spain, university sector
General scepticism	"Maybe I'm the black sheep of hydrogen! Finally, many others live off of it, I don't'… I only devote a small percentage of my time to hydrogen.... Some have the role of defending hydrogen so internalized that no longer distinguished character from actor." *Spain, private sector* "I have a wind park producing electric energy that I cannot inject to the electric network, but with this electric energy I can produce an alternative product. (…) It is like a factory that can produce a product A and a product B at marginal costs. But well, to whom would you sell product B? The hydrogen sold in market nowadays is synthetic (and has no requirements)[there is no demand] and the market is saturated. The market does not need more hydrogen and yours will be twice more expensive. Who is going to buy yours?" *Spain, private sector* "We think hydrogen is still in a very experimental stage. There is no market. They are still all as demonstration projects to date." *Spain, public sector*
Competition with other technologies	"There are other alternatives more tested and economically less expensive and with an easier maintenance and a much longer life. Specifically in Galicia, hydraulic pumping is something that is widely used as an energy storage system comparable to hydrogen where you have water, as in the case of Galicia, and is much less complicated and much more studied, and much easier. The hydraulic pumping can be done with any renewable sources such as photovoltaic, or wind. In Galicia we have a lot of wind and you can do hydraulic pumping…" *Spain, university sector* "I know very few real cases using FCHs for primary power; it is a very expensive technology." *Spain, private sector*
Storage	"What sometimes is missing with technology is the initial phase of market. If there is no market, there is no technological development. I think that the key for not developing hydrogen market is the distribution (…) it is very difficult to carry a gas like hydrogen, it is difficult to store". *Spain, university sector* "The problem of hydrogen storage is, and will probably continue to be for decades, one of the questions and one of the most important technological and scientific challenges: to achieve the storage of gas at atmospheric pressure." *France, public research sector*
Inefficiency	"By using hydrogen fuel cells to generate electricity, a great deal of efficiency is lost. The truth is that technology will have to advance further on these issues." *Spain, public sector*
Performance characteristics	"The fuel cell has a lot of limitations. It is very expensive. It is very delicate. Life is too short. It is very unstable. These are the biggest problems. There are no real possibilities for use. You can use hydrogen everywhere, but the fuel cell is very delicate, it is not robust, and very expensive." *Spain, private sector* "Compared to electric mobility: hydrogen vehicles consume at least three times

	more power compared to electric vehicles." *Germany, university sector*
Safety	"I think there is a perception at the general level, you talk about hydrogen and people get scared. And it really is less dangerous than gasoline or natural gas. It is an unknown technology and people are afraid about new technologies." *Spain, public sector research sector* "Users will not accept hydrogen, they find it too dangerous." *France, private sector* "Hydrogen is not a popular gas for people. When they hear about hydrogen they think with explosions and these things. Hydrogen is manipulated and transported and no one realize, but it is part of our daily live. In practice, there were many barriers and, for me, the most important are distribution and storage". *Spain, public sector*

4.1.3 Hydrogen supply and use: expectations

The key expectations for hydrogen are generally positive, with market development in the relatively near term, albeit with national differences and specificities. However a considerable number of interviewees also perceived an uncertain future for hydrogen. The next figure summarises the wide variety of additional, specific expectations (Figure 26).

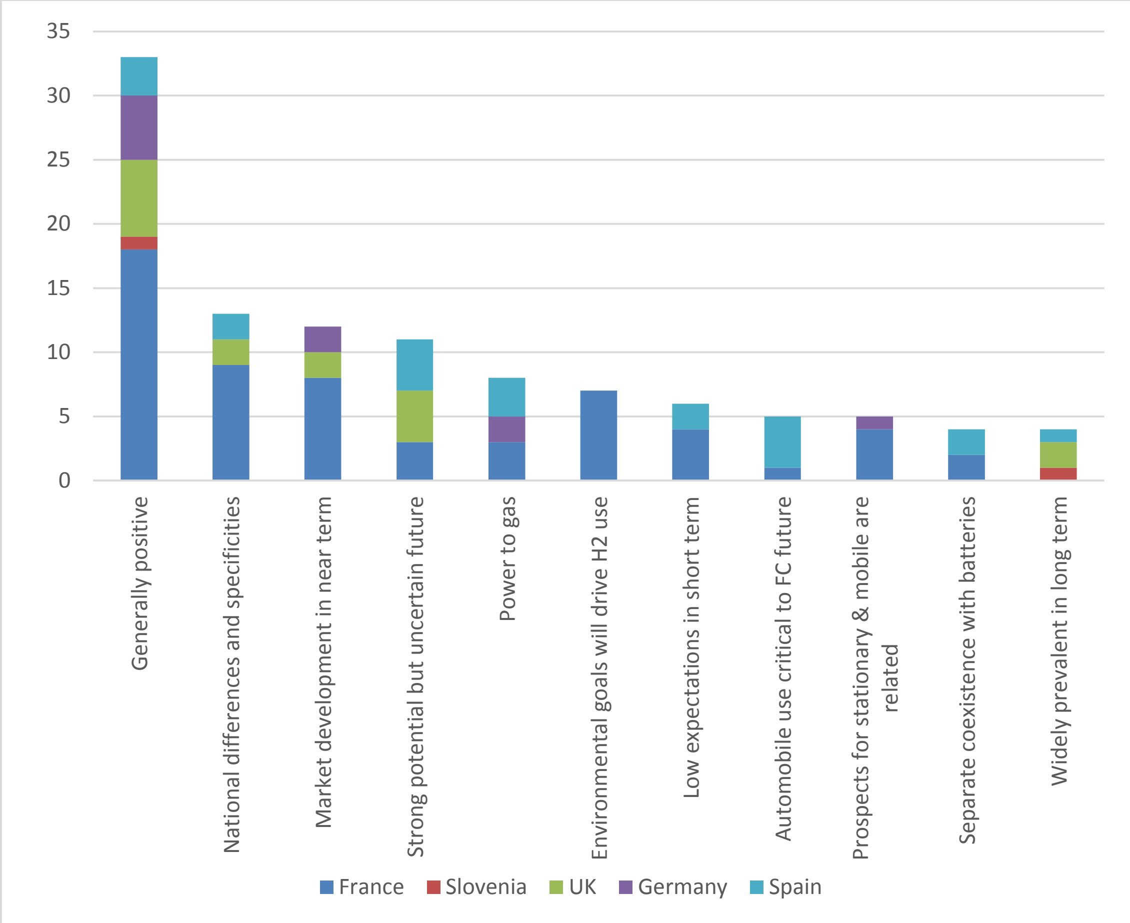

Figure 26 Hydrogen supply and use: expectations (higher incidence)

In more detail:

Dimension	Quotes from the stakeholders
National differences	"I do not have a crystal ball ... what is clear is that Spain is not in the game. When we want to do it, it will be already done. Germans and others will have already done it… It will happen as in the automotive sector, we are only good component manufacturers." *Spain, private sector*
Hydrogen as playing a key role in future	"Hydrogen will play a tremendously relevant role in the future." *France, private sector* "Hydrogen technology will play a key role between green energies in France, as much as the others renewable energies, since it is a complementary solution." *France, public sector*
Economic opportunities	"I think there are opportunities for the countries that lead on these technologies. We see Germany going for hydrogen in a big way. Scotland has also done that. We've got clusters in Aberdeen, Orkney, and Fife. We are placing ourselves well. There will be jobs created and opportunities for

	providing services and exporting as well. These are all opportunities that will come." *UK, private sector*
Awareness of hype cycles	"All the project partners were enthusiastic for trying to promote the technology, all of them saw business opportunities. Except universities partners, because they only did the monitoring part. All of the technologic partners, oil companies, buses manufacturing companies, manufacturing fuel cell companies, hydrogen producers... The project was launched at 2001 and started operating in 2003, all of us were enthusiastic because we thought it would be the technology of the immediate future." *Spain, public sector*
Storage as key	"Some hydrogen applications could mean a game changer scenario for countries like Africa, in where energy could be stored at a lower cost." *France, private sector*
Supply chain benefits	"I think the energy sector, the people who install the hydrogen equipment, and people who design it, designers, installers and manufactures will have the most opportunities. It is the case that the electrolysers in our project are imported from Canada so we need to grow a UK supply sector as far as we can. There are opportunities for UK companies to grow their businesses." *UK, NGO*
Consumers will follow	"The consumer will positively welcome this type of technology if the governments encourage its use." *France, private sector*

4.1.4 Hydrogen supply and use: recommendations

Interviewees focussed on hydrogen supply made many recommendations, of which by far the most frequent was that more government and political support is required; followed by a perception of the need to inform and engage stakeholders; and additional R&D to reduce costs (Figure 27).

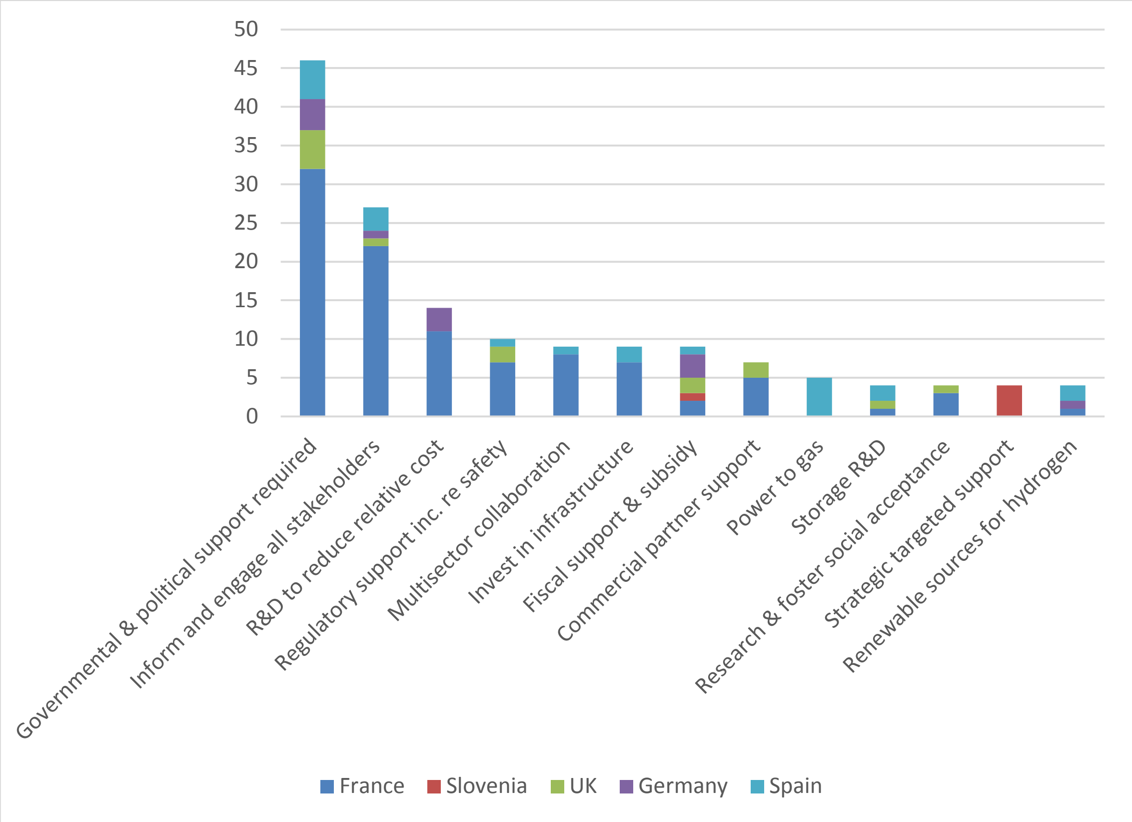

Figure 27 Hydrogen supply and use: recommendations (higher incidence)

In more detail:

Dimension	*Quotes from the stakeholders*
Strategy and policy	"At the political level, a common European development strategy is indispensable; right now, each country has defined its very own development plan and objectives." *France, private sector* "Without strong public policies and firm industrial choices, the future of hydrogen market remains uncertain." *France, public sector* "The main obstacles are politics. If the government would provide a very safe framework for investment at least safe energy policy for hydrogen." *UK, community sector* "Politics are now needed to support the market development and support possibilities for storing energy as e.g. wind farms have to be turned down repeatedly as too much electricity threatens to overload the grid." *Germany, private sector* "To arrive at a point of massive adopting, the first would be political willingness and commitment. It is complicated, but it's the main thing. After that, it would be a matter of public investment to create and support network for hydrogen supply

	(hydrogen stations). It can be done as a petrol station but first there must be some political and financial support to the policy level. Investment, incentives, whatever ... Fulfilling these two things, the interest of the private sector will follow." *Spain, private sector* "We need stronger environmental constraints for carbon market (as happens in Paris, for example, regarding the pollution of the city)." *France, public sector*
Standards, regulation, legislation	"We must define a European standardized value for the percentage of hydrogen in the gas networks". *France, private sector* "Recognize hydrogen as a biogas, to encourage its development for resale on the gas network." *France, public sector* "There has to be a huge amount more regulation put in place and guidance put in place around the technology. That's a big issue while it's so much emerging. All standards have to be very robust and clear and well developed." *UK, public sector* "Grid usage fees have to be reconsidered for this technology (electrolysis is no electricity consumer, but provides a service which goes back to the electricity sector). No competition with conventional power suppliers is possible. Start-up funding and financing is important, for example a scheme with priorities for feeding-in with regard to CO2 emissions." *Germany, private sector* "Most of Europe doesn't have a huge gas network and so it doesn't make sense for a European directive that says we are going to switch everyone to hydrogen." *UK, public sector*
Public investment	"This is not the repetitive cry for public money, saying, yes, of course, we want to be funded, but the market won't run if it is not stimulated in this way." *Germany, private sector*
Costs	"The safety issue should be tested also through insurance companies, to see what annual costs are expected." *Slovenia, public sector research*
Sustainable sourcing	"The third challenge would be to achieve a revolution in the sustainable production of hydrogen. Many people do not care about it. Right now, the hydrogen is produced via reformation. It is quite efficient but produces CO2. It is no longer toxic but is a greenhouse gas. So the current production of hydrogen has a CO2 footprint. Someone may think it is very easy to produce hydrogen from water with a solar panel. All sustainable. Yes, but I do not see anyone who wants to invest on this. Because it is very expensive. Not because of the efficiency of the solar panel ... The problem is the cost. It has gone down, but still…" *Spain, university sector* "If HFECV begins to spread out, but the hydrogen continues to be generated from natural gas and oil, it will not help at all." *Spain, private sector* "If you are going to build large scale wind farms that's going to take a long time and it's going to cost you a lot of money. The CCS option with its benefit to capturing industrial carbon alongside capturing carbon from hydrogen production

	and power generation if you want to do that as well offers you a number of options for keeping costs down." *UK, public sector*
More demonstration projects	"There has to be a larger range of key projects demonstrating so we understand some of the challenges that we need to address if things are going forward on a larger scale. There's got to be more plans; people have to learn from at a relatively small scale that we can apply to a larger scale. Something like our project, we could do it anywhere but multiply it up." *UK public sector*
Power to gas	"The proposal would be hydrogen produced from the excess of renewal energies that could combine with CO2, from the atmosphere or from the CO2 generated by thermal power plants. Through Fisher-Tropsch reaction you turn that into synthetic methane and you can directly inject to the gas network. This way you have transport, storage and even stationary uses fully guaranteed because all natural gas technology is valid." *Spain, private sector*
Storage	"We think that the key is integration with renewable energy". *Spain, private sector* "The second challenge is to achieve a safe and efficient onboard storage of hydrogen. So far, the most efficient way was cryo-compression, a physical method where you compress and cool. Cooling is energetically expensive. Hydrogen tanks are bulky. There is progress but I have not seen that there is a break here. It is another bottleneck, safe, cheap and efficient storage. You need a material that can absorb and then de-absorb the hydrogen…Hydrogen is the lightest element in a car, but you need safety. Safety would come from the fact that hydrogen would be stabilized in a material that would stabilize it safely, taking from it the explosive power." *Spain, public sector research* "Political authorities believe large-scale storages will only be necessary from 2030 when there will be a 60-80 percent share of renewable in the system (energy system models are too simple). But from the technical side there is already a need for these systems. Substitution for conventional power plant for control energy [grid balancing] is needed." *Germany, private sector*
Collaboration	"What happens is that like with other new technologies, all it needs is a concerted and comprehensive development of many participants." *Spain, public sector research*
Maintain momentum	"The most important thing to say about this subject is that a tendency has been established for the last 5 years and it must not stop." *France, private sector* « Le vrai problème au niveau politique sont les échéances électorales : les promesses des uns ne sont pas forcément les engagements de autres » : "the real problem at a political level are the electoral promises: the promises of some people are not necessarily the future commitments of the others". *France, private sector*
Communication and	"Degree of efficiency (only 60-70 percent), but this applies to a lot of transformation processes. For the population, information is needed and

engagement	arguments in order to explain this to them." *Germany, private sector* "We are going to have to transport hydrogen. How accepting are people going to be of hydrogen on the road? How accepting are people going to be of pipelines or infrastructure? Our infrastructure is going to have to radically change – are people going to accept that? We need to start explaining that now." *UK, community group* "Studies to evaluate the social acceptability of H2 technology should be encouraged in the various regions of France." *France, public sector* "Media support is essential to sensitize the grand public on hydrogen advantages." *France, private sector* "The first question from the public when we talk about hydrogen is 'Is it a bomb, is it safe?" *UK, private sector* "It is necessary to keep on working on sensitizing communities to ensure the future application of H2." *France, public sector*

4.2 Fuel cell stationary applications for heating and electricity

4.2.1 Stationary applications: perceived strengths

Interviewees strongly emphasised the utility of FCHs for uninterruptible and / or portable power as a key strength (Figure 28). To a lesser extent, reliability and efficiency as well as positive perceptions and environmental advantages were also emphasized with German respondents being dominant in those categories.

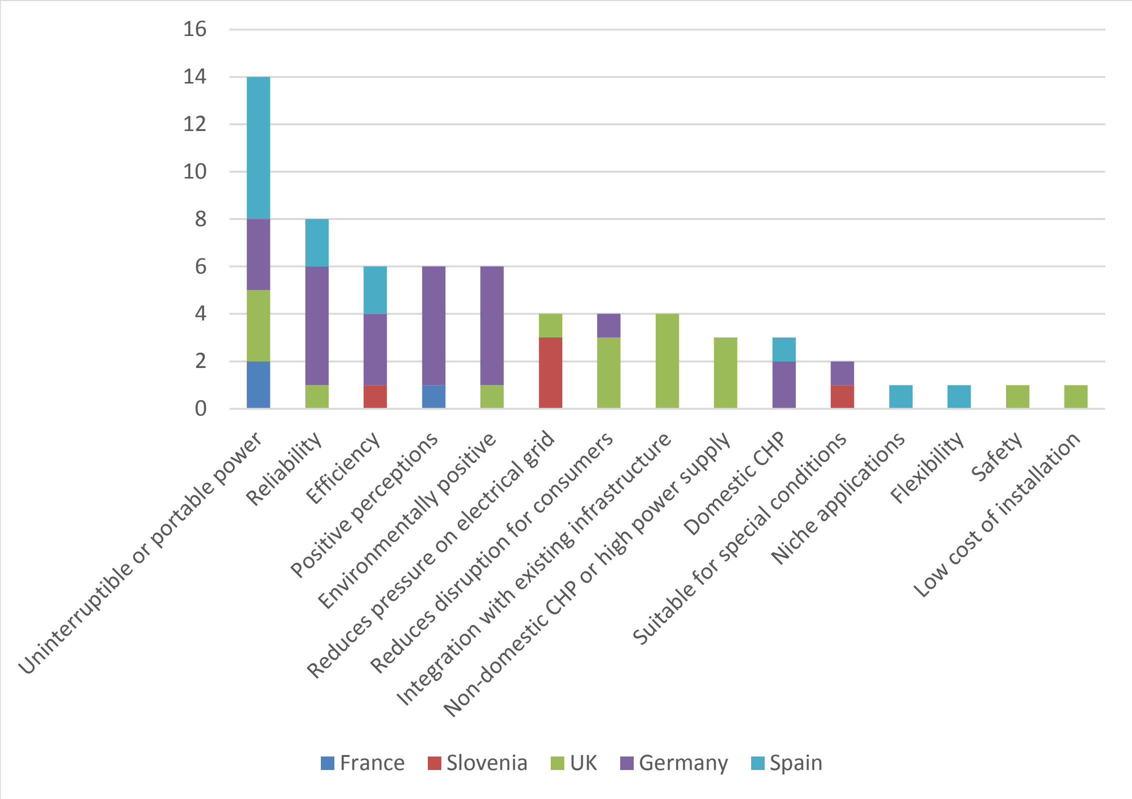

Figure 28 Stationary applications: perceived strengths

In more detail:

Dimension	*Quotes from the stakeholders*
Reduces disruption for consumers / convenience	"If you compare that with hydrogen you are talking about someone coming in one day and changing the boiler for new boiler in much the same space, operates in much the same way as the previous one did. Changing potentially the gas hob for a new gas hob with different burners on it. Then carry on as before. In terms of disruption that is hugely more attractive and a much easier sell than trying to convince people to take heat pumps." *UK public sector* "Now if we are talking about heat networks the disruption there come in terms of years of roads being dug up as heat networks to install and there is quite a concern about how practical that is going to be in London and places like that where we know what is under the ground and it cost us a huge amount of money per metre to dig pipes. It's very difficult to see either of those technologies taking over from gas. Now that's not to say there isn't a place for pumps or heat networks clearly of the gas grid. Heat pumps are probably the only sensible solution. For urban areas and high rise buildings heat networks are very good way forward there. What do you do with 60 to 70% of the population in the middle that are currently on the gas grid in less dense areas but the probably isn't the space to be putting in huge numbers of noisy heat pumps. That's where hydrogen technology could win hands down." *UK public sector*

	"From the user's point of view, it is a very clean application. Using natural gas, using a soft type battery, it is a very clean application. With a small equipment, it can be like a gas boiler we have in the house, I can cover my needs of hot water and electricity. From the point of view of business opportunity it has a bright future. But again there is the economic aspect. And this is very short term. There are experiences in Switzerland and Japan where this type of technology is quite advanced and there demonstration experiences. Projects with 200 households are investigating the reliability of the equipment, how consumers respond, etc." *Spain, university*
Advantages over batteries	"The other alternative technology is the traditional battery system, but in this range of power (between 100 and 500 W), there is no comparison possible in terms of autonomy. The stacks of traditional battery systems produce too many parasitic losses." *France, private sector*
Flexibility	"...most significant advantage is as a transition technology between carbon based fuels and green fuels: a fuel cell will happily convert from running on one to the other as greener fuel becomes available." *UK, private sector*
Decentralised production	"If you've got a number of homes that are operating fuel cells as a way of providing both heat and power, then you can local generation rather than having to do local reinforcement of the electricity grid. I think at that point it becomes very attractive proposition but you need the take up of electric vehicles to be a lot higher than it is today." *UK, public sector*

4.2.2 Stationary applications: perceived weaknesses

Interviewees overwhelmingly cited cost as the key weakness of the stationary applications. Secondly, the complexity of the system as well as limited awareness and support by regulators and governmental stakeholders are mentioned. These were followed by several weaknesses at similar frequency of occurrence and included for example inefficiency of the system, the challenge of finding commercial partners and perceived and 'actual' safety (Figure 29).

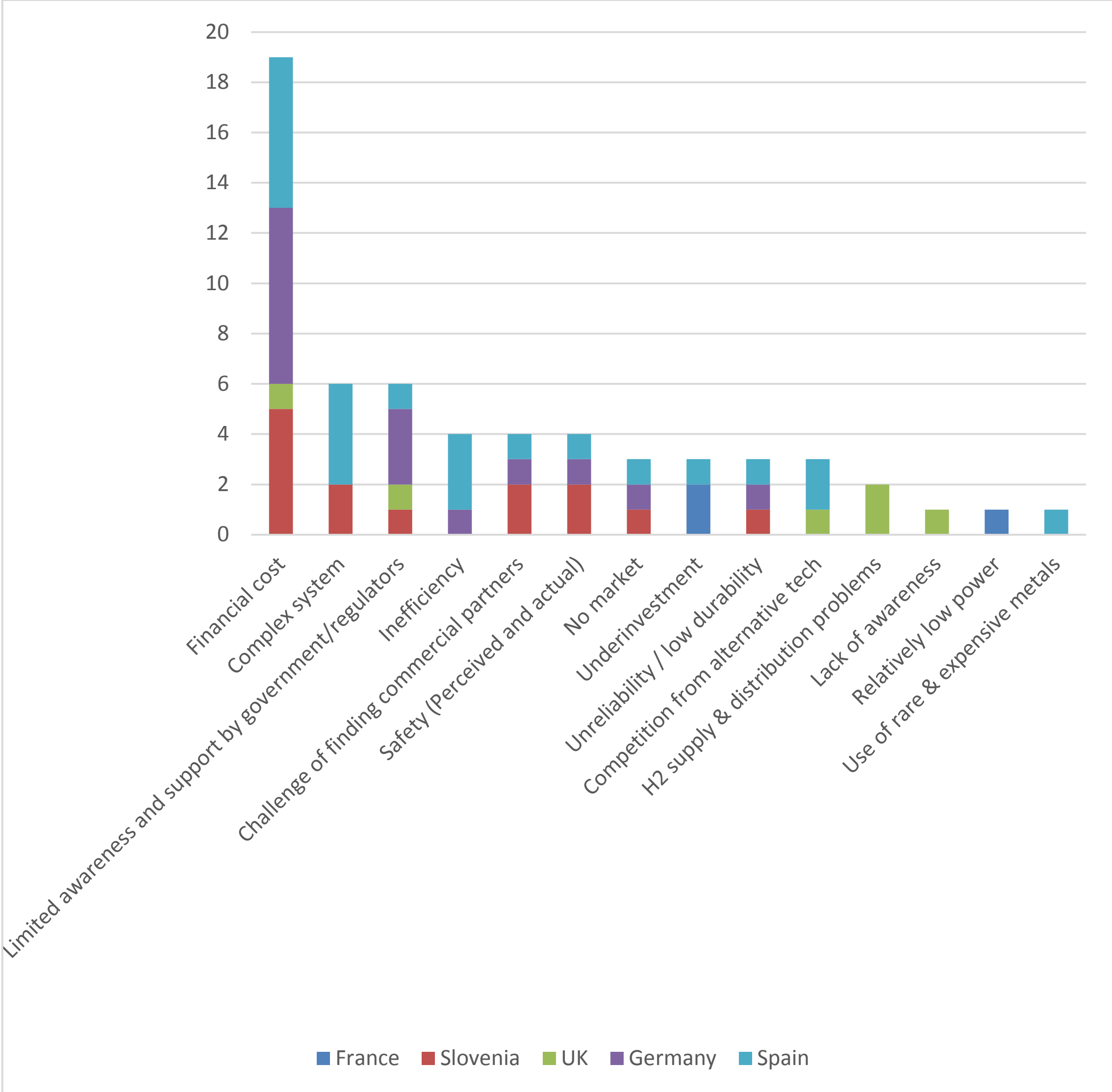

Figure 29 Stationary applications: perceived weaknesses

In more detail:

Dimension	Quotes from the stakeholders
Cost	"The price comes mainly from the battery, although the price of the electrolyzer is not negligible. The electrolyzer that has a more similar dynamic to a wind farm is a PEM electrolyzer. PEM electrolyzers are priced above alkaline electrolizers." *Spain, university* "In stationary applications, fuel cells we are talking about have live cycles of 5,000 hours, tops. 5,000 hours of life on stationary is a ridiculous thing. Because it means that every year, you have to change twice the fuel cell, it has no sense at all". *Spain, private sector* "I was in Yokohama at the hydrogen congress in 2005. At that moment, Honda, Mitsubishi and others were rehearsing fuel cells… electric cells of 1.5 kilowatts. In

	Japan houses are almost like the living room of a Spanish house… And imagine the situation in US, with a cell of 1.5 you will just illuminate the porch. For this reason it is complicated, and now the tendency goes to a self-generation photovoltaic". *Spain, private sector*
Inefficiency	"In stationary applications, the mistake was in not doing the efficiency calculations properly. Or evaluate which was the best alternative. Because at the end, if you picked up the electric power generated by a windmill, a wind energy or electrolysis, being optimistic, we could think up to 70% yield. It was necessary to compress a minimum amount of hydrogen and then a conversion element with a combustion gas turbine. This would at most give 30% back. So the whole barely reached 20%. 20% yield cycle in a system that was intended to be an alternative to storage, no. It did not exceed any cost benefit analysis." *Spain, private sector*
Small markets	"Market potential of this application is limited (e.g. after all 4600 radio base stations in Germany are equipped with the system, it is over)." *Germany, public sector*
Regulation	"And then there is the problem of handling the hydrogen. The current legislation is far from clear as to hydrogen, or at least it is not easy. This is also very important. If for installing a domestic fuel cell in your house you need to study 200 laws, you are going to get crazy." *Spain, university* "A major problem was also the distribution network. Where do we place the hydrogen refuel stations? In London they had a big problem in the CUTE project because they were not allowed to install a refuel station in the city centre. In Brussels, still today, in many public car parks, gas vehicles are not allowed to park… So don't even think to park a hydrogen car". *Spain, private sector* "We have many regulatory constraints today via the ICPE nomenclature". *France, public sector*

4.2.3 Stationary applications: expectations

The tone of expectations was mixed. Positive expectations were voiced as often as negativre ones. Negative expectations came only from Spanish interviewees while the positive ones were coming from a mix of countries; low expectations in the short to medium term formed the third largest fraction (again many from Spain); this is then followed by expectations expressing a positive view on near-term market development for the technology from various countries again (Figure 30). More specific expectations refer to hydrogen being used as a storage medium as key to the take-up of stationary applications (UK respondents only), the expectation of niche uses first, uninterruptible supply systems as one such niche (German respondents only), and some kind of inevitability perception of market deployment.

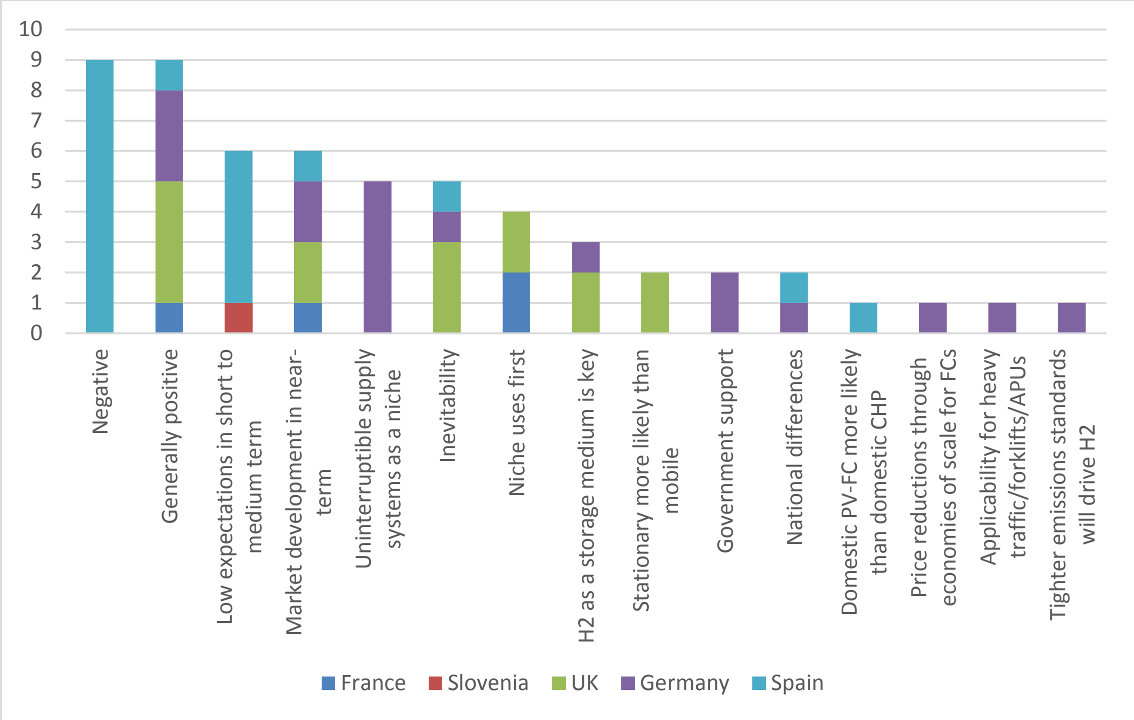

Figure 30 Stationary applications: expectations

In more detail:

Dimension	*Quotes from the stakeholders*
Unproblematic	"I think the issues of micro CHP and probably hydrogen vehicles if you make those attractive as an offering to people there's nothing dramatic that needs to happen on a national scale. An electricity supply co. could very easily turn round and say we want to encourage the uptake of micro CHP in this area because it's going to be cheaper then reinforcing the electricity grid. Effectively encourage that to happen on a house by house basis with some people taking it up and some people leaving it. I feel there's less challenge there." *UK, public sector*
Stationary applications dependent on mobile success	"Despite the various applications of hydrogen, its development has been focused in the transport and mobility sector, which has contributed to promote its benefits as an energy carrier. For this reason, its success will largely depend on its development in this sector." *France, private sector*
Unlikely at a domestic level	"For residential applications I think it is very difficult. The technology was not cost competitive and I don't know if it is now. Everything is now electric; there is also central heating, etc. I do not know ... the market is not ready for an evolution there ." *Spain, Foundation* "Injecting hydrogen into the network I see it very feasible, very possible and relatively close, but fuel cells at homes I cannot see it .... I see much more likely that hydrogen is introduced in vehicles, and then people will start getting used to. But the issue of fuel cells at home I see it very distant now." *Spain, private*

	sector
International competition	"Currently, it is a 'dry period' as it will take some time for the market to develop. This is different from the situation in other countries, e.g. in Japan, where much more of these appliances are already installed and running. And the Japanese manufacturers are now also entering the German market so that this may have a negative impact on Geman manufacturers as they are more developed." *Germany, university research sector*
Portable power	"People don't know that this exists, if people become aware that it is possible to take your laptop anywhere without charging the battery, with just putting in a liquid occasionally, they would be delighted!" *Spain, university*
Competition with alternatives	"I think there are other solutions ... as solar thermal. I think there are really other options… Governments should invest more in those… Governments shouldn't give grants to FCHs research, if manufacturers are not developing FCHs is because they think there is no future for FCHs… almost in stationary applications. For transport perhaps is different, I do not know." *Spain, private sector*

4.2.4 Stationary applications: recommendations

Interviewees' main recommendation was to provide stationary FCH technologies with more sustained and coherent Government (including European) support (Figure 31). Bracketed together, this appeal for Government support clearly dominates. Appeals for enhanced public and regulatory support and understanding follow, with regulatory support particularly relating to issues of safety. In short, most of the recommendations are for supportive governmental action.

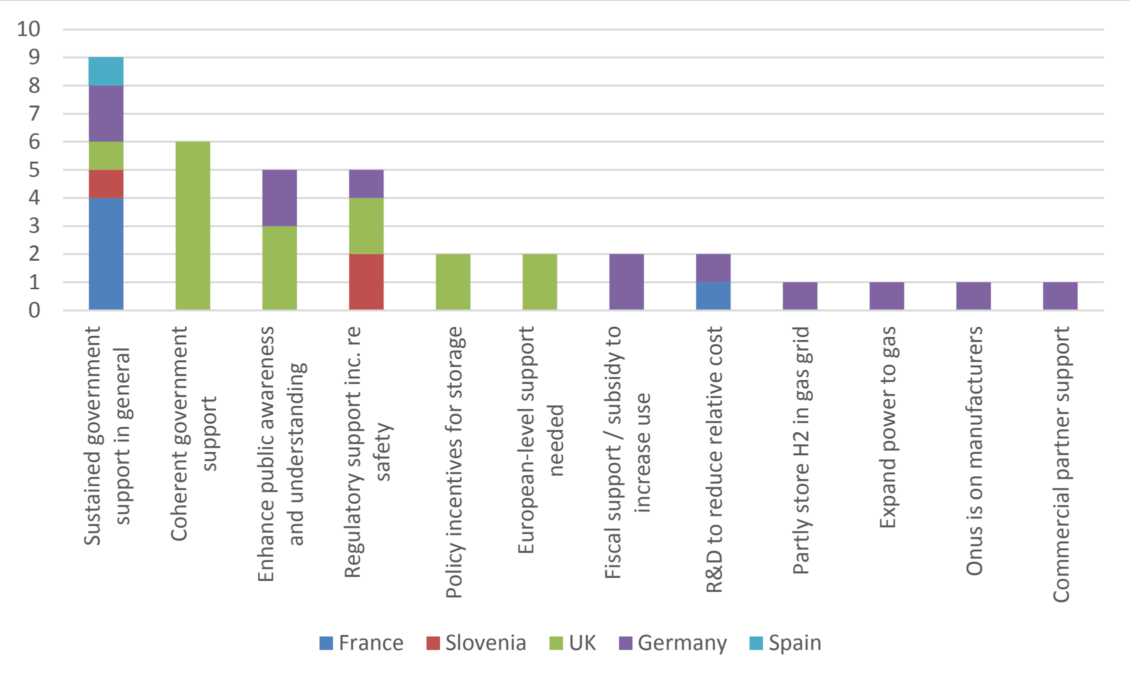

Figure 31 Stationary applications: recommendations

In more detail:

Dimension	*Quotes from the stakeholders*
Understand the potential markets	"There would certainly need to be a real show of proper holistic level of understanding if we're really trying to bring this kind of industry here. You would need to understand what still fits because we would need to have a diversification in the market. We need a wider level of understanding of what issues companies have and how to get companies to try and focus more on the UK market areas and be pragmatic about what we are going to be able to attract." *UK public sector*
Regulatory coherence	"For example, I went to ask for regulations and there is a regulatory gap in relation with fuel cells, and they do not even know what a fuel cell is, then ... I have interesting stories about it... But I miss some kind of support, we are used from the beginning to fight alone for the illusion we have to renewable

	energy. We believe they (renewable energies) can play a very important role in the future". *Spain, private sector*

4.3 Fuel cell transport applications and related infrastructures

4.3.1 Transport applications: perceived strengths

The top strengths of mobile FCH applications are focused on technical performance: long range, short refill times, high torque, etc. A further emphasis is on lack of local emissions or that the technology is generally good also compared to alternatives. Figure 32 lists a variety of additional perceived strengths, such as integration with existing infrastructure or suitability for specific fleets.

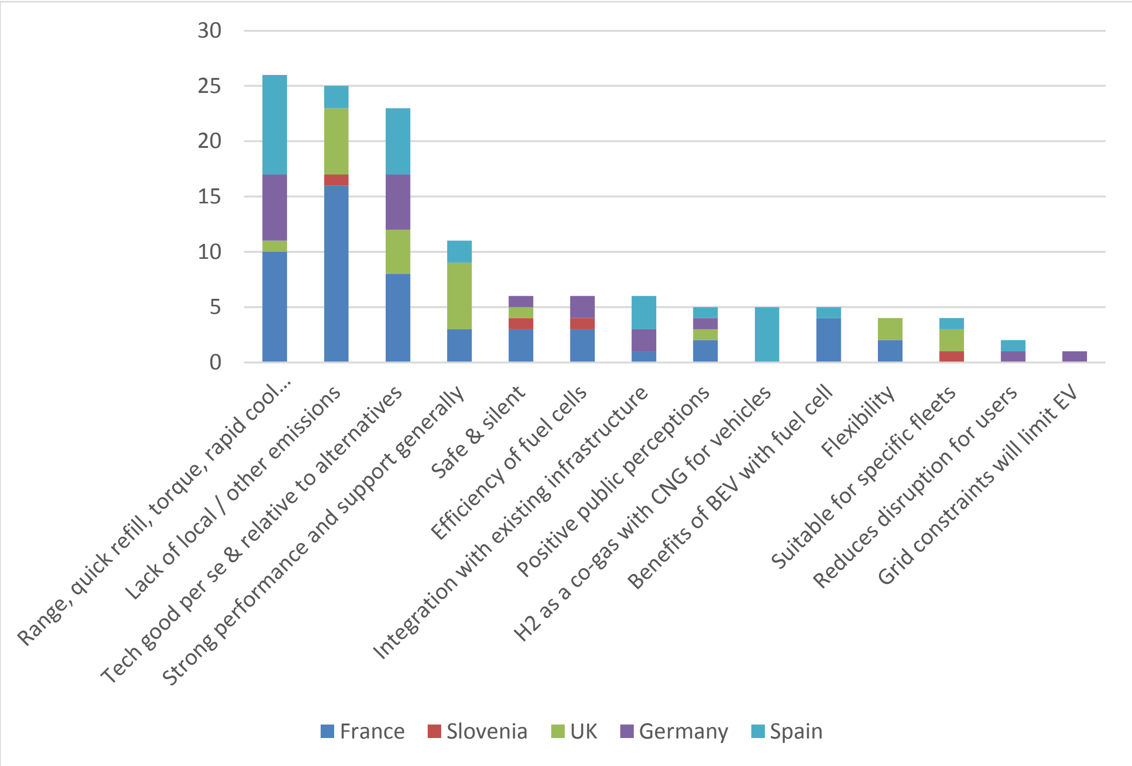

Figure 32 Transport applications: perceived strengths

In more detail:

Dimension	*Quotes from the stakeholders*
Operational performance	"It is easy to recharge; a full hydrogen refill can be completed in 3 to 5 minutes." *France, public sector* "Short refuelling times, high ranges compared to battery-electric vehicles. For the (potential) customers, fuel cell vehicles are more similar to conventional vehicles than battery electric vehicles and thus more attractive." *Germany, private sector*

	"Electric cars pose many problems; people do not want to be waiting an hour to load the battery. In addition, if you have a long journey to change the batteries is not feasible, besides when the battery is low, the car does not have enough power. The power of a hydrogen fuel cell car is always the same, the maximum. The load of FCHV is around 2 or 3 minutes, as it is in an ordinary car." *Spain, private sector* "When you charge a conventional forklift truck it spends 8 hours. Thus, you need a second forklift truck. However, fuel cell forklift is charged in 3 minutes. If in a conventional warehouse they need to work in 3 turns of 24 hours a day… 100 forklifts, 50 charging and the other 50 working. With a fuel cell forklift they would need 70. It offers an advantage in the initial investment". *Spain, public sector research*
Technological maturity and performance	"Hydrogen technology is mature, the hydrogen car works, storage of hydrogen required for the car autonomy is acceptable, is done." *Spain, private sector* "There is an energy transition on its way and some large industrial sectors such as aeronautics or naval have already developed systems based on hydrogen. As an example, Alstom has developed a fuel cells powered train." *France, private sector* "The hydrogen vehicle is an electric vehicle, because you have an electric motor, however, instead of having a battery to store energy you have an hydrogen tank and a fuel cell. As the vehicle moves it needs electricity, it consumes the hydrogen tank, combines it with air in the fuel cell and produces electricity. The only waste is water from the fuel cell. So in this sense, it has all the advantages of electric vehicles. These vehicles are silent, zero-emission, have a constant and continuous acceleration without having to change gears. Electric motors have a very high efficiency, etc. But FCEVs have also other advantages that EV does not have. Recharge time is between 5 and 10 minutes. It is very easy to charge, as a conventional car. And the range is between 500 and 600 km. And next year we will have 700-800km. It has the same range as conventional gasoline or diesel vehicles." *Spain, private sector*
Social acceptance	"Before, people were afraid of hydrogen technologies, but all the pedagogical period is over and today, they are ready to use them; they actually ask for new technologies." *France, private sector* "There is always a concern regarding people perception of safety, but in fact people accept pretty well these new technologies. Our experience is that people sat quietly, had no bitterness riding on a hydrogen bus. When a brand provides a vehicle people tend to assume that it is safe. It is similar to natural gas buses. They have been very well accepted. Even better, because people notice that pollute less and not make noise." *Spain, private sector* "The technology is at a commercial stage and now, with the right level of support, it would be able to be used in the mainstream and a competitor with other electric vehicles. It's in a stronger position because of the flexibility H2 fuel cells provide because the mechanism of fuelling and driving a vehicle are all in line with what

	people are expecting to run their vehicles – they don't have to plug them in overnight." *UK, public sector* "On the professional side, we have former users of electric vehicles who complained about their autonomy and that today are fully satisfied with H2 technology." *France, public sector* "I think, the greatest potential or a big advantage is the fact that the end user don't have to adapt to the technology compared to what he is used to." *Germany, private sector*
Environmentally benign	"It's a green technology that will reduce pollution significantly." *France, university* "Its main strength is based on its low environmental impact, which would reinforce the European / global commitment to the environment." *France, private sector* "Fuel cell vehicles could help mitigate climate change and other environmental issues, including reducing the contamination of groundwater and urban noise pollution." *France public sector* "France has a strong willing to introduce this new solution into the market in order to address the major issues of climate change." *France, university* "It is easier to produce methane from hydrogen, being a less polluting solution for internal combustion engines." *France, private sector* "Hydrogen technologies are more environmentally acceptable than some others (e.g. Biofuels, bio-methane, etc.)". *Slovenia, private sector* "It reduces greenhouse gases. This is important. That's regarding sustainability […] If we see the use of hydrogen in the transport, this would have benefits in highly polluted urban centers. Also for ports, which also require a decrease of CO2 emissions. By ships and others. It could be useful also in specific road transport sectors. There are niche markets in the areas of refrigeration trucks…" *Spain, public sector*
Energy security	"I can tell you that the fuel cell will lead us to energy independence. We will stop importing oil. Instead of buying foreign oil, we are going to invest in R&D inside the country. Spain is going to develop its own fuel. You can do it from a source of renewable energy, fuel cells are highly efficient." *Spain, private sector*
Potential for high power putput	"The market for larger vehicles has always really being on converting conventional and so there the cost was incredible high and it never delivered what was needed because of payload restrictions and ancillary power requirements. So hydrogen might be the alternative technology suited to those sort of applications. So whether you fixing roads or taking teams to manage environments or move around large building sites and taking building materials, it's those sorts of applications that the main stream low carbon market around electrics doesn't grasp around this present point in time." *UK public sector*

4.3.2 Transport applications: perceived weaknesses

Financial cost dominates in terms of perceived weaknesses, followed by limited awareness and support by regulators and government and competition with other technologies (with which could be bracketed the specific, already-existing option of electric vehicles for urban use); lack of infrastructure including fuel. Figure 33 lists a range of more specific perceived weaknesses, including inadequate or excessive regulations, codes or standards; safety; technological unreliability/durability; lack of markets and lack of public awareness.

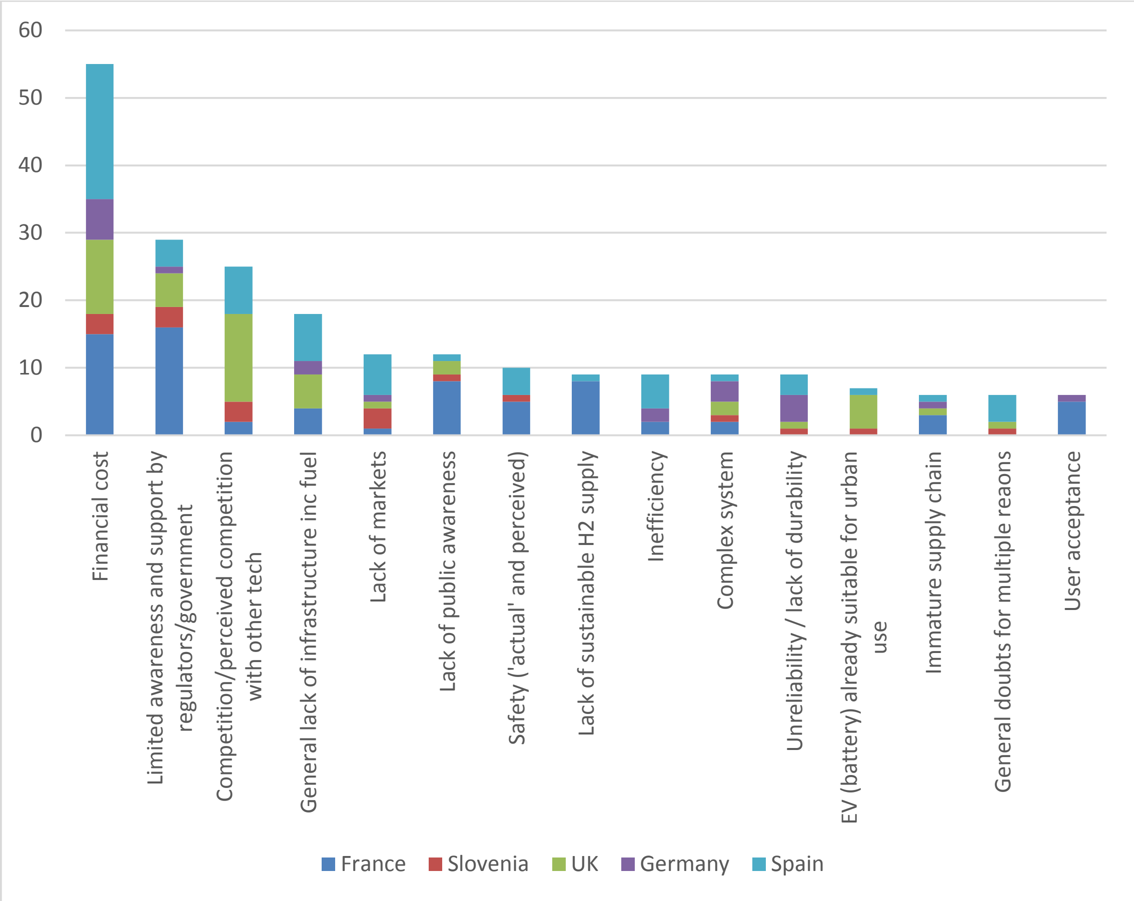

Figure 33 Transport applications: perceived weaknesses (higher incidence)

In more detail:

Dimension	*Quotes from the stakeholders*
Cost	"The only downside of the technology is the cost of production and storage, which are expensive because they use very expensive materials and techniques." *France, state research organisation* "The associated costs of H2 technology are very expensive. Currently, the installation of a refilling station costs 1.5 million euros, hence their sparse availability." *France, public sector* "For transport applications, except fleets controlled by the government, such as

	buses or garbage collection, the rest of the vehicles have to be bought by the middle class... Are the prices affordable for the middle class?" *Spain, private sector* "I think, everyone is lying to each other: The costs which are communicated do not reflect reality; it functions badly in daily operation; thus the existing problems should be named in order to change something." *Germany, university* "Hydrogen fuel cell buses were tested in Madrid, Paris, Barcelona a few years ago. It was the perfect demonstration that the technology didn't work. Why? Was the fuel cell not working? No, the fuel cell did work, but the bus costed a million euros. Which means it costed five times more than a normal bus. But also (and this was said by the local agency), you needed to have two mechanics day and night. That means that what we're talking about a technology that is not worthy. So forget about it." *Spain, private sector* "It was expected that these costs will fall, but I do not see that have slashed enough" *Spain, private sector* "With a diesel truck, the provider can offer the route up to 3 euros per km. With a hydrogen vehicle it has to offer it to 12 per km. We are not going to pay that extra cost only for introducing a new technology." *Spain, public sector*
Operational and scale-up limitations	"Hydrogen technologies are efficient and green but rather complex." *Slovenia, university* "...inability to secure funding, failures with technology and ability of cities to embrace technology and have proper roll out programme and strategy, plus lack of spare parts. A robust supply chain is required – logistics. No one knows the total cost of ownership over the lifespan of the buses – this unknown is a big problem for operators." *UK public sector* "Right now, manufacturing ceramic, making functional ceramics. It's a complex process. Right now, there are no many ceramic products based on technological or functional ceramics. Therefore, it is complex. And therefore, it is difficult to scale up. There is little experience because in the end you have a product and if you have to change it, it is very complex. Because you have to change the whole production process. Here is the key." *Spain, university* "The main difficulties that H2 technology is currently facing are battery conservation, available pressure, technological uncertainties related to the engine of the vehicles, battery development for ranges longer than 600km." *France, public sector* "The fuel cell is very delicate, very complex, very unstable, short-lived and very expensive. Does it make sense? Yes, in remote (hard-to-access) locations." *Spain, private sector* "And then also there is one thing that nobody wants to see, or at least I don't see it into the analysis of energy balances, and this is the cost of compressing hydrogen at 700 bar. Because that is not trivial. This needs a monstrous power. Nobody pays

	attention to this." *Spain, private sector* "The technology-readiness-level is at the level 6 or 7 with regard to buses: more than a demonstrator, ready for daily use, but there are still malfunctions, there are still technological risks." *Germany, public sector* "First, technologists have to solve the problem. Because the main barrier is still the development of the technology. The problem with hydrogen is that the fuel cell has a short life and it is too expensive to produce”. *Spain, public sector*
Competition with alternatives	"While they are doing that, in another part of the forest, clever people are finally getting round to cracking how do you deal with the refuelling and range limitations of batteries.” *UK, commercial association* "In sectors I am more familiar with there is a lot of inclination towards Electric Vehicles. In fact other sectors complain about that. The people in the natural gas argue that the only alternative is LPG. And they're right. You will not make freight transport in electric trucks. But thinking in the city, the best option for changing transportation is the EV.” *Spain, public sector* The truth is that today, still above 300km, fuel cells are not alternatives in loading time or in weight or volume. Of course, this can evolve. But it is always much cleaner, much easier to get an electrical connection.” *Spain, private sector* "There are two or three business niches that might have been interesting: forklifts, communications towers, but I don’t see a market niche for them now. We are focused on lithium batteries." *Spain, private sector* "Someone in the X transport department said we don’t care how it’s powered all we care about is the lowest cost that we can run buses for." *UK, partnership* "The three 2nd hand car lots nearest to my house they’ve got a mix of petrol, diesel, they’ve a mix of automatic and manual. They haven’t got a mix of electric or hybrid or hydrogen." *UK, commercial association* "For LPG, the installation cost is very low. Repsol and Cepsa are installing it in their own gas stations. It is an option that is there. And the transformation of the vehicle is very simple. For 1000 euros one can transform the vehicle and consume lpg. Furthermore, as is subsidized, it is an option that interests you ... It's money, not consumption, but there is a cost savings. Although I think it is a temporary solution, not a final solution." *Spain, public sector* "Natural gas would be taken from the distribution network and when it reaches the refuel station, they will compress them to introduce it to your car. No new transport networks are needed at all, it will be used the existent one. And this is one of the advantages, the existing network and distribution of natural gas.” *Spain, private sector*
Lack of infrastructure	"If there is no hydrogen available through refueling stations, there will be no hydrogen fuel cell cars. Nobody is going to buy a car with hydrogen. And if cars are

	not sold, no company is going to install hydrogen refueling stations." *Spain, university* "I think we tracked down 3 hydrogen refuelling points. There might be 4 or 5 but I think a couple of them are only available by appointment." *UK, commercial association*
Safety	"The second problem is the storage of hydrogen. Storing hydrogen is complicated. As I said before, is very volatile and then it is a system of 700 bar pressure, and I am convinced that it is a serious safety issue and I cannot see a practical, simple and inexpensive solution." *Spain, private sector* "Hydrogen is an energy carrier that doesn't arouse the interest of the general public, since people do not trust in its safeness. Therefore, its success in the area of mobility will be limited." *France, private sector* "We would never install hydrogen refueling station. Because the issue of security is another problem here. Because it is super explosive. It's very scary." *Spain, public sector* "Another problem (which also exists for electric vehicles) is that you cannot hear them at the street. It is really a problem… They are already creating regulations to create an artificial noise, because it has become an important topic of safety". *Spain, private sector* "What happens is that we are more used to store electricity in the form of batteries than in the form of hydrogen. Especially in a vehicle. There is a lack of knowledge of what can really happen." *Spain, private sector*
Scarce metals	"The first problem is that PEM fuel cells use platinum as a catalyst. I made some rough estimates taking into account the needs of platinum in a car with conventional fuel cells… Could we have a market full of FCHVs? Apparently not. Platinum is a very rare and very expensive metal. Platinum is scarce and, therefore, is very expensive. The amount of extractable platinum in the world would not meet massive demand with the current fuel cell technology. Even if the amount of platinum needed is lower, if we have a mass production, the price of platinum would rise and would produce a detrimental situation. There could be a scarcity curve. I do not see it clear. We should have catalysis without platinum." *Spain, university* "The pieces of the fuel cell contain instead of plastic or rubber, titanium, platinum, siridio, carbon ...it is very expensive to work on that. You need a very strong investment to advance the technology." *Spain, private sector*
Effect on battery life (BEV+FCH)	"There is a challenge with regard to demand shifting using your electric vehicle as this will probably wear out the batteries more quickly and if you have £5000 of batteries in your car do you really want it to last 2 years rather than 5 years because you are saving a few pennies. It's not an immediately clear that this is the right way or that the consumers are going to find this attractive unless we can be much surer about the battery life of these devices in the future but logically its clearly go to be

	the way to go." *UK public sector*
Unavailability	"It's quite difficult for the consumer. You can read about the vehicles. You can understand the benefits of driving one of them but then when you look into it and there's not possibility of getting one of those vehicles. Then the end users think I might just stick with my old diesel or petrol car. I like the idea but I can't get one." *UK university*
Environmental	"We wanted to transform city buses in hydrogen buses but we thought that the city was going to be filled with water vapor. This was a problem, as this is a greenhouse gas. So we decided to go electric." *Spain, private sector*

4.3.3 Transport applications: expectations

Interviewees were strongly divided in the tone of their expectations, with generally positive expectations equalling low expectations in the medium to short term (Figure 34). Within these, UK interviewees expressed more optimism than pessimism and Spanish interviewees the converse. Among the more specific expectations, all of much lower incidence: the expectation of specific vehicle fleets being the first to use FCH technology; niche uses first or only etc.

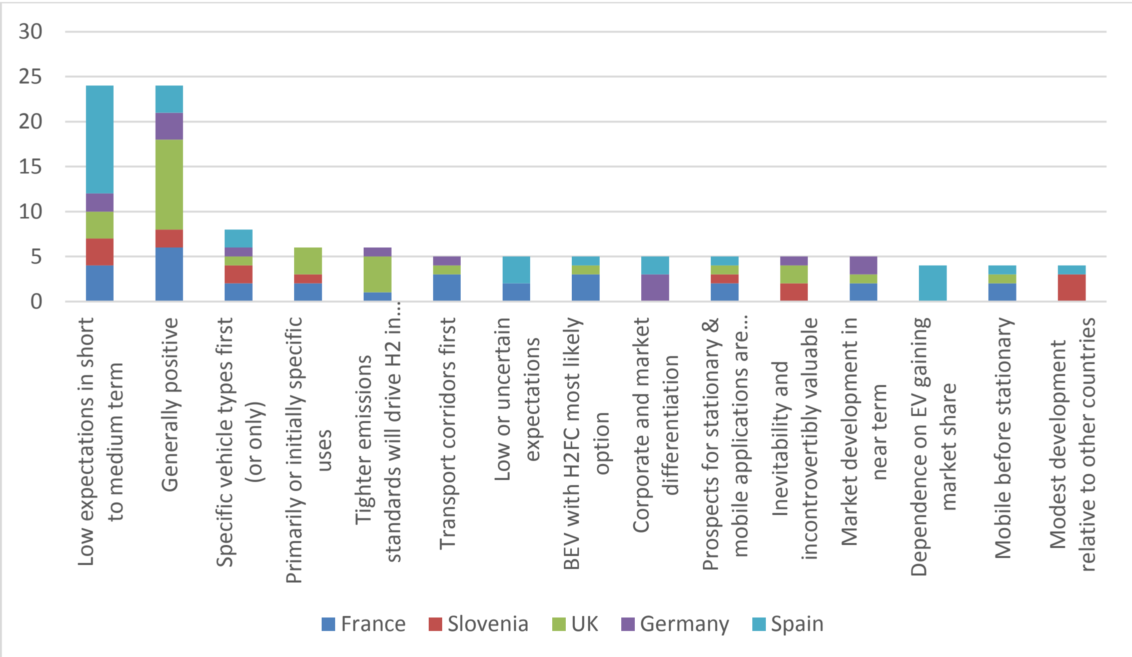

Figure 34transport applications: expectations

In more detail:

Dimension	*Quotes from the stakeholders*
Medium to long term	"On the producer side, the supplier side of the technology we do not have the necessary capacity that is needed. One major company is now

prospect	consequently following this path and they expect it to be relevant on the medium term, but many others are still playing on a low level. You cannot make billions from it at the moment, the time span is more towards 2030." *Germany, state research organisation*
Distant prospect	"When we assist the Fuel Cell Hydrogen Joint Undertaking meetings, they have reports and all say the same:‘ yes, because of the volume effect it will drop from 10 euros to 3 and bus will drop from 1 milion to 400.00 euros‘ but at the moment we are talking about hypothesis". *Spain, public sector* "In the short to medium term, the EV is going to prevail. For road transport I think liquefied natural gas. As an alternative to conventional fuels I see more possibilities in EV because now there is more supply of vehicles and the cost of the recharging infrastructure is much more affordable. Manufacturers, due to the issue of CO2 emissions, are positioning themselves in favor of electric vehicles. It is the most immediate." *Spain, public sector*
Cost	"As this is a new technology, its costs are very high. Over time, these will decrease and it will become accessible to everyone.” *France, public sector* "I do not think it is a problem of cost. It is a problem of economies of scale. Not always the optimal technology is imposed. For example, the combustion engine car was imposed against the battery, at the beginning, due to an opportunity, and once it developed is very difficult to change. This change is starting, but it will cost a lot to get to occur. If electric batteries are going to win, the hydrogen will have a problem." *Spain, private sector* "Of course the costs of the vehicles are still too high, sure there are a lot of problems to solve regarding the infrastructure (reliability, operating costs, the technology itself). […] But in the long run there is no alternative from my view.” *Germany, private sector* "Unless the government promotes the hydrogen infrastructure, I'm entirely sure that it will never be developed. It took a lot of effort that companies such as Endesa invest in a network of electric charging stations, so imagine now to plan the hydrogen infrastructure, which is far more complex and far more expensive." *Spain, private sector*
Enviornmental drivers	"... there are European legislation around emissions and the more that those emissions regulations are tightened and enforced the more it’s going to make it more attractive for people to be operating, zero emission vehicles be this hydrogen or battery electric vehicles." *UK public sector*
A part of	"Cars will probably have moved to a car share and car clubs basis, and people will have changed their attitude to car ownership. Any safety

future living	concerns will have been long addressed. Local governments will play a key role in the provision of hydrogen and shaping public attitudes, supported by national governments and major companies." *UK, partnership* "In order to see transport going leaps and bounds you would want to see some form of fuel cell technology being used in F1 motor racing. You would want to see some type of adoption and use of fuel cells and hydrogen to really give us a different and more flexible way of living. I don't see what we do today being what we do in the future. I can see changes in storage, balancing the grid transfer may be a thing of the past and totally different. I see hydrogen and fuel cell being part of it, with digital." *UK, public sector* "There will be policy in relation to public transport for the requirements for low carbon or zero emission vehicles. There should be infrastructure in place and integration with petrol or other refuelling stations. There will be a supply chain in terms of manufacturing and creation or location of fuel cell companies in the UK, and a robust supply chain for materials, technicians, repairs, health and safety requirements for vehicles. There will be a better understanding by users of the safety repercussions of vehicles. There will be a second hand retail market for vehicles and there will be fuel cell renovations replacement so that if a fuel cell breaks down it can be brought back into service." *UK, public sector* "... it is perfectly possible to have hydrogen vehicles in the future. It has been achieved in the past. A concerted development of technologies that are self-supporting. For example, the development of electricity. You needed the bulb, the generation and the distribution of electricity. It looks tremendously similar to the case of hydrogen. And they did it. Why? Because it was clear that that had to happen." *Spain, university*
Niche and larger specific markets	"In France, we try to develop this technology in niche markets." *France, private sector* "They are using fuel cells for very special applications because they can satisfy needs that cannot be satisfied with electric batteries. Fuel cells are superior in energy density. So applications such as drones, where you do not care about money, you don't need to recharge, but simply to go and return ... there are applications where fuel cells will have a role. In isolated sites, niche sites, military applications in space, there are some applications that can work." *Spain, university* "Where I see more future is in portable and low power mobile applications that do not require a large refuel infrastructure, which is one of the big

	problems." *Spain, state research organisation* "I think that buses will continue to be the prime zone for improving the hydrogen technology, which will greatly knock on to other things. It will be very much welcomed with cars and particularly on the use of cars socially, such as car clubs and pool cars for businesses, and possibly specialist taxi companies." *UK, partnership* "We have to start with the big vehicles; the buses. [...] buses are big in consumption, intensity of use and they depend on one decision taker. Here is the issue. Then we will reach the passenger cars." *Spain, private sector*
Hydrogen as a co-gas (CNG)	"Car could be powered with CNG or with hydrogen; we consider it can be market for both. The issue here is to reduce pollution. CNG has emissions but less than oil or diesel. And hydrogen has not emissions at all". *Spain private sector* "At the end no one thinks that all cars will go with hydrogen, CNG may be an alternative, and at the end, I think it may be room for hydrogen and natural gas." *Spain private sector*
Policy as key	"A key question here is what level of importance will governments attach to moving towards low carbon technologies? The cheapest option is to continue with modern technology diesel cars etc. If we want to see decarbonisation of the transport sector it will be driven by governments which will see quicker roll out of low carb technology." *UK partnership* "I would see it commercialising within 10 years, that would be the hope, but that relies on what policy support it secures." *UK public sector*
Unknowns	"All these things will happen progressively. I think prices are going to be competitive or to match other technologies. At that time hydrogen applications will reach a niche market. In transport I think the niche will be bigger, maybe around 25% of the vehicles. For stationary I would say 10 or 15% of overall generation. Maybe in 2050 oil is over and instead of having 10 or 15% hydrogen we have to produce hydrogen at full speed." *Spain public sector research* "It's very complicated. I think the majority of fuel cells are mature enough to be produced. This has been demonstrated. The problem is that obviously there is a status quo. To change the system is not easy. It requires an investment, of course." *Spain, public research sector* "If there is a collapse of the network, literally, it would be no longer a decision to enter or not enter in the technology. It would be a necessity. It

	would become a need." *Spain, university* "From my point of view, the hydrogen car will be the trigger for a change of the energetic paradigm. Oil, or due to climate change or because oil is over, there will come a point that although the hydrogen is expensive or renewables are expensive but it will have to balance prices." *Spain, private sector* "... we have involvement in both hydrogen and electric battery, but hydrogen has proven itself to be a strong competitor against battery driven. What I think is interesting is that these two technologies have been competing to some degree and it may well be that other technologies come in, in a very disruptive way. In particular, driverless vehicles may come in very, very quickly and that may dramatically reduce the need for numbers of vehicles so it may have an enormous impact. It may free up resources to reassess hydrogen or it may mean emissions go down because there's fewer vehicles on the road lessening the impact." *UK partnership*
Large players as key	"... There is a certain blockage until the car companies show their cards, there is uncertainty and nobody wants to invest a lot in developing a technology with so many uncertainties". *Spain, private sector*
H2 as fuel feedstock	"Hydrogen may have its niche but not used directly, but converted to other chemical component that could be used, for example, for heavy transport, for local urban transport ... This way, storage systems do not require very high pressure, as pressures made time ago by Linde, who only considered liquid hydrogen as the only way to distribute hydrogen". *Spain, private sector*
Conditional on battery improvements	"As long as the (lithium-ion) battery remains with the current limitations... the fuel cell has a future. If in the future we have batteries that load quickly and with a highest energy density, I do not know if the hydrogen will have an application in the electrical world." *Spain, university*
Synergies with BEV	"For the FCEV to have a niche market, it needs the EV. If there is no significant deployment of electric vehicles, hydrogen will not be able to ever go to the market. [...] . FCEVs will play a role when we have a transportation fleet more electrified, and more renewable energy." *Spain, private sector*
Hydrogen as a co-gas in CNG	"Let's imagine for a moment that this conversation is two years from now and we already have a bus mixing hydrogen and methane. [...] People will see no difference. You will see the same bus, with the same gas cylinders in the roof." *Spain, private sector*

Will not compete with BEV	"Some research centres are focusing on developing vehicles for urban environments. But there they cannot compete with the electric car. There is little that can be done there." *Spain, public sector*
Auxiliary power	"In X we are working on different applications, but with the crises we are few workers and no money. But we are applying hydrogen fuel cell in air transport. Specifically in two aspects: for electric propulsion in unmanned vehicles (drones), and generation of electric power on board of commercial flights. *Spain, state research organisation*
Social / public perception	"It is important to not break the neck of this technology in having a negative public opinion, in the sense of: It does not work." *Germany, private sector*
Mixed possibilities	"The diesel now provides a lot of kilowatts per liter. I am not sure about FCEV. With electric cars you would need very big batteries. When you experiment with each of the technologies, you see that each has its pros and cons. We think that the key is to find the optimal mix of technologies. There is no solution for all the situations. Of course, the diesel is better for both short and long distances." *Spain, public sector*
Realising visions	"When I give a conference I have a presentation with one slide about the main car companies that in 2000 they had planned to introduce fuel cell vehicles. They had planned that in 2015 they would sell the first commercial hydrogen vehicle. And it has happened. It seems that the automotive industry achieved what they had proposed. That's where there are more expectations, the introduction of hydrogen from the automotive sector, from there, hydrogen will begin to raise". *Spain, foundation*
Transport corridors	"We focus on transport corridors to mesh, step by step, the whole territory". *France, public sector*
National differences	"I estimate the role of this technology in Slovenia will be somewhat less than in the neigbouring countries (Austria, Germany etc), but much stronger that in the south-eastern parts. Let's say we will be at about 50% of the level achieved in Germany." *Slovenia, university*

4.3.4 Mobile applications: recommendations

Interviewees again advocated governmental, political and regulatory support, including support towards cost reductions; investment in refuelling infrastructure together with more communication and engagement generally and of publics were also advocated (Figure 35). Recommendations can also in many cases be inferred from interviewee comments listed above.

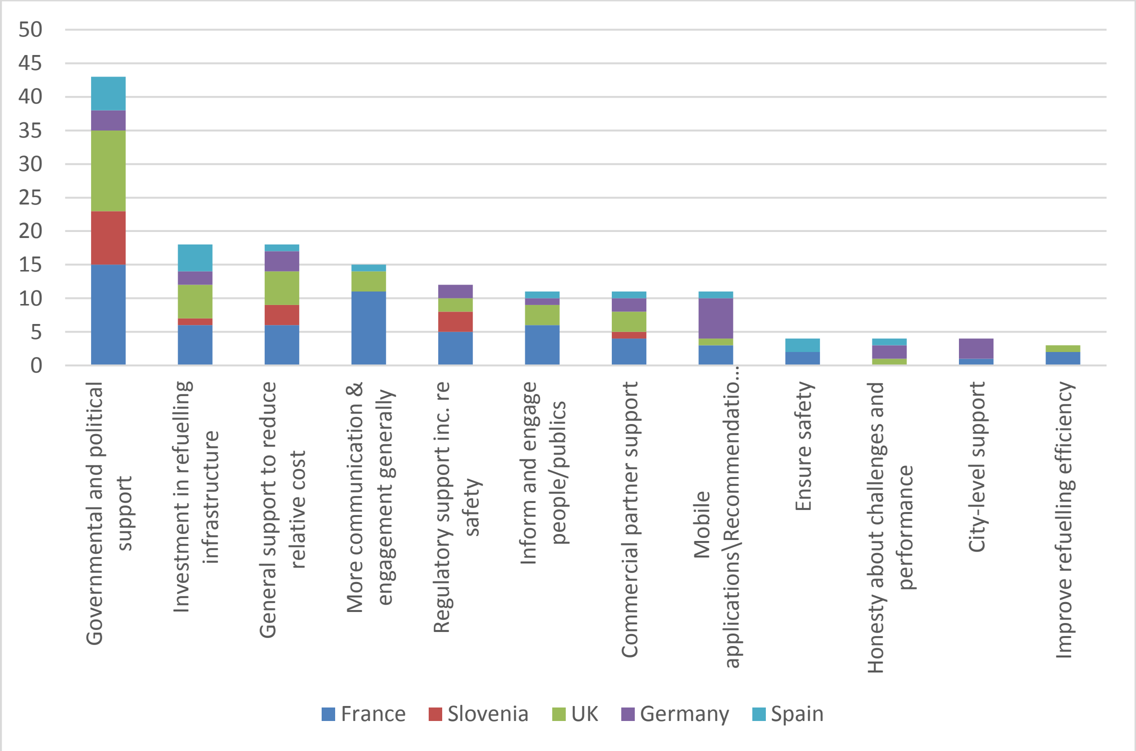

Figure 35transport applications: recommendations (higher incidence)

In more detail:

Dimensions	*Quotes from the stakeholders*
Common standards	"Car manufacturers and refueling system companies must agree on a technology standard so consumers can actually adopt it." *France, private sector*
Skills	"So a lack of skills that needs to be addressed to ensure if there was the infrastructure and the vehicles or even stationary fuel cells that the skill within the workforce to be able to maintain and grow the infrastructure as well and also maintain the vehicles." *UK education sector*
Public infrastructure investment	"Hydrogen technology is mature, the hydrogen car works, storage of hydrogen required for the car autonomy is acceptable, is done. These cars pass the same safety tests than any other. The problem is that they are expensive. The car is expensive and above all is that there is no infrastructure. Public initiative to promote infrastructure is needed." *Spain, private sector*
Volume of H2 production	"There has to be enabling infrastructure for hydrogen to take a more prominent role in the future transport sector in Scotland. If there's enabling infrastructure and matching supply of hydrogen it will be big. My real concern is the commercial volume of hydrogen production." *UK public sector*
Combination with battery electric	"The electric car is the main competitor but so far is not competitive because of the reduced autonomy, high volume and weight. Hybridization is required."

vehicles (BEV)	*Spain, public sector research organisation*
Learn from BEV	"Battery electric vehicles are becoming more common, but I think we should be taking lessons learned from battery electric vehicles as to how we should bring fuel cell vehicles in." *UK public sector*
View alternatives as complementary	"H2, GNV (CNG) and electric technologies should not be brought into confrontation, each one responds to a specific need". *France, public sector*
Investment	"Companies should take this technology seriously. It represents significant opportunities." *Slovenia, university* "End-users should not invest in the technology until the prices are comparable with other vehicles." *UK, public sector*
Policy	"Government should have clearly articulated its approach, joined up between relevant agencies and organisations, and be clear on the way further forward for the technology; , what's expected in carbon savings and costs, acceptability of emissions, clarity for investors and the public and corporate boards." *UK, public sector* "Political institutions should create more financing programs for this type of technology to collaborate in its development and to encourage its use by consumers." *France, public sector* "This technology will achieve a great success if companies and public institutions promote the research, the construction of infrastructures and manufacturing of vehicles, and the diffusion to the grand public of information about its great benefits." *France, private sector* "Government has changed the funding regime from grants to loans. Whilst this pushes the commercialisation and pay back agenda it does increase risk dramatically". *UK, private sector* "Governments always fall shy of directly stepping in and becoming the retailer of alternative fuel." *UK, commercial association* "Need a level playing field with other alternative fuels such as Biogas which gets support, whilst synthetic methane receives no support". *UK, private sector*
Consider used vehicle market	"At some point that vehicle will be considered by the operator or transport for London to be passed its prime in the world leading city and then it's sold on somewhere else. It's possible that large heavy vehicles that could be sold on re-engine or refitted or something that could preserve its 2nd hand value and that might be a more enticing prospect than thinking of going straight to the mass car market." *UK, commercial association*
Public communication and engagement	"It is necessary to inform consumers about its benefits and the security measures that have been taken in this regard." *France, private sector* "Program creators don't understand the need for public awareness raising, If

	this had more attention paid to it, it might help with public acceptance of the technologies." *UK private sector* "No acceptance issues expected in the population if technology works like conventional technology and if it is not more expensive." *Germany, public sector*
Skills	"So a lack of skills that needs to be addressed to ensure if there was the infrastructure and the vehicles or even stationary fuel cells that the skill within the workforce to be able to maintain and grow the infrastructure as well and also maintain the vehicles." *UK education sector*
Create demand via infrastructure	"In France, we shouldn't wait for the vehicles to be on the streets to start installing some refueling stations (maybe we could copy the German model)." *France, partnership* "It's the problem of the chicken and the egg. People do not buy hydrogen vehicles because there are no hydrogen stations. There are no stations because there are no people buying the vehicles. And manufacturers do not sell the cars because without hydrogen stations, no people is willing to buy them. You need to break this vicious circle by establishing an initial deployment of infrastructure that allows people to have a network of refueling stations and car manufacturers to sell the cars...the authorities need to establish the pertinent infrastructure." *Spain, university*
Co-gas in CNG	"We can say know, ok, let's start introducing hydrogen step by step. We can have hydrogen up to 23% of the mix, and that looks good. And then maybe there are stakeholders interested in using this mix in buses. Then a major in a big city can decide to adopt this technology in their fleet. And then companies will require this technology (hydrogen with methane in NGV). And that will be the way to bring hydrogen to the reality without any technical risk." *Spain, private sector*
Hard to imagine	"Just establishing the regulation for the electrical charging stations took two years and a half of work. I cannot imagine the regulations for the installation of hydrogen refueling stations. And then, the investments, the implementation…". *Spain, private sector*
Oil price	"The price of oil is crucial for the future of fossil fuels and can push governments to bet on alternative energy sources." *France, private sector*
Automanufacturers as key	"It is a large-scale issue related with the automobile industry... When they introduce some technology, it immediately decreases in costs. It is question of large-scale production. As soon as the automobile industry integrates fuel cells technology, it will be extended to other sectors. In Japan, for instance, FCHV are being sold out. Prices are not excessively high, similar to a mid-range electric car, about 60.000 €). Again, the problem is the distribution network, but I think that in Japan and in the United Kingdom that is being done every well… They have the advantage of being an island... This does not happen for example in

	Germany, who is also working on its network but of course the problem is what happens when cars cross the border and go, for instance, to Poland…". *Spain, private sector* "... (We) define(d) the parts with highest cost impact. The result was that FC costs present about 50% of all costs and recirculation pump with AC-DC controller have high impact. We estimate that costs of the FC will be reduced by automotive producers due to economy of scale. All other components in hydrogen system requires dedicated development to optimise the costs." *Slovenia, private sector*
Decision time	"Gradually over time there's been an increase in awareness that this is a technology that is serious and worth considering. We not at a stage where any decisions have been made but there is clearly a momentum building that this is something we need to look at seriously and we should consider it amongst all the other various options in meeting the demand for low carbon." *UK public sector*

4.3.5 Project specific issues and situational observations

The purpose of this code category is to record comments that are largely specific to projects or that did not fit well with the other codes, but that are so specific as to not merit a new code. For example, with respect to hydrogen supply, five interviewees referred to and emphasised the importance of funding and RD&D structures that support multi-sector collaboration; four stressed that involving commercial partners is key (Figure 36).

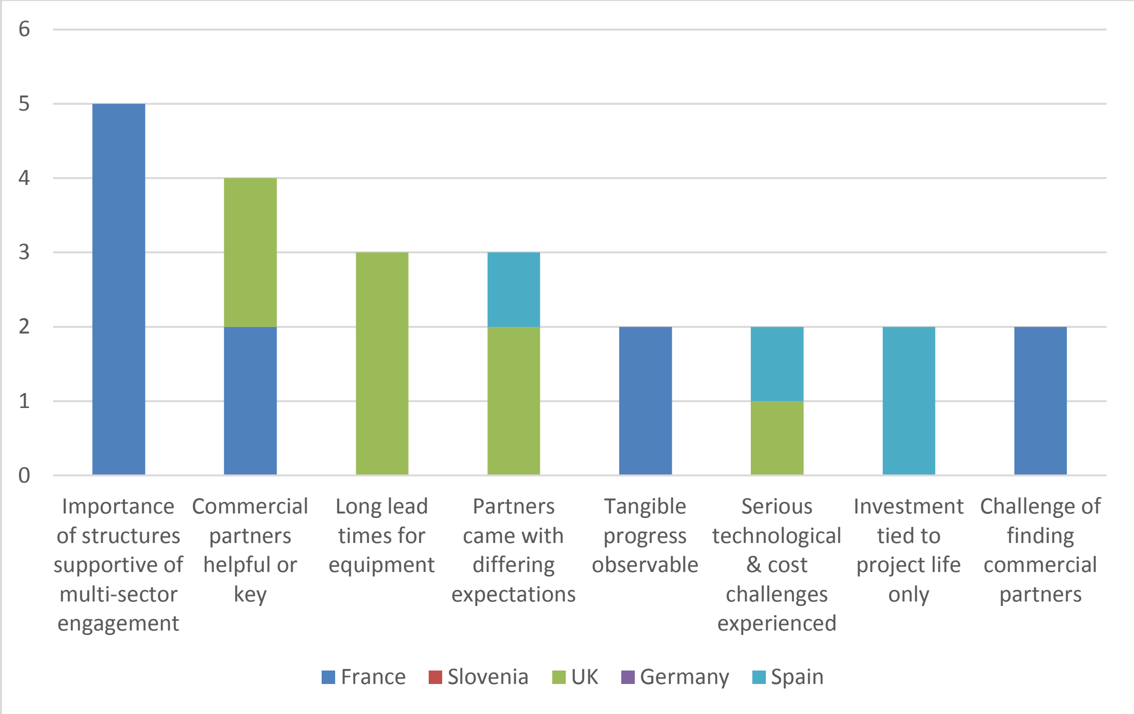

Figure 36 Project specific issues and situational observations: hydrogen supply and use

Across interviews focussing ontransport applications, six interviewees reported specific national observations and five that projects lead to an open exchange of ideas (Figure 37).

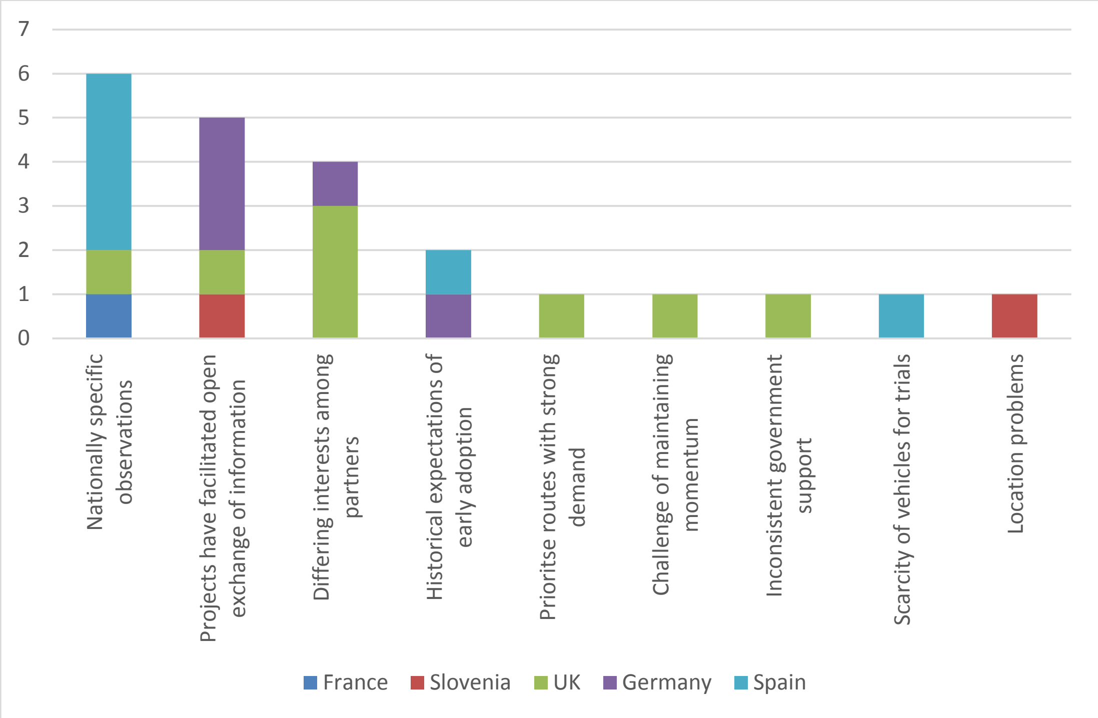

Figure 37 Project specific issues and situational observations:transport applications

In terms of additional, project-specific detail (mobile applications), interviewees referred to: the long lead times being experienced in projects: e.g. for critical parts of refuelling stations there are only one or two suppliers globally; and the problem of investment being limited only to the duration of a project:

> "Several things happened; on one hand the development of hydrogen was not as expected and, on the other hand, different regulatory changes, especially in Spain where renewable energies led us to a complicated situation. At that point, the company decided the closure of those lines that do not see priority in R & D with immediate applicability.” *Spain, private sector*

Commercial partners do not perceive or find markets

> "The project has not been successful due to the lack of cooperation from companies… they considered that it was not profitable.” *France, university*

> "France advances slowly in this technology because national automakers do not get involved." *France, private sector*

> "The North American market is more active and (forklift trucks with hydrogen fuel cells) have been implemented successfully. The same companies that sell forklifts are then invested in by European companies such as X. Then, they come to Europe and they do not achieve the same results". *Spain, public sector research*

> "Governmental support has been easier. In the private sector it is difficult to find financing because of long deadlines for the return of investments in the project. It is

not a question related with hydrogen… it is a development in four years at least and is more complicated." *Spain, private sector*

"I distrust a lot of Governmental interventions. States should make the function of guiding policies, especially if they want a better environment. That seems fine... I agree that they encourage, promote studies, give their opinion (if it is qualified) but I am against interventionism. People thought they will hit the jackpot with renewables in Spain; because of the government bonus, but Government withdraws. I am in favor of tax policies but if they are transient, incentives programs for 4 years are enough ... An incentive program is need for maturing the technology, but if this technologies does not mature, and then… off. State cannot be a risk investment Fund."*Spain, private sector*

Challenge of engaging commercial partners

"I went to US to see if we could get a fleet of Prius converted to hydrogen to implement some national experience. Because we were not going to buy a dozen Prius just for us, but if we could develop a national project, maybe we could use a couple of vehicles ... But it didn't work, it came to nothing. There was no way that some bus manufacturer vehicle told me when we could have a vehicle". *Spain, private sector*

5 Summary and conclusions on country- and country-grouping level

The country differences in qualitative stakeholder opinion are subtle and are best observed and presented through the condensed, comparative analysis presented in section 4. Comparative analysis split by technology type shows that the views and expectations of stakeholder are influenced by their policy contexts and the degree of national activity and support. To show this on a country level inevitably involved some repetition with other parts of this and other deliverables, but nonetheless has the advantage of enabling a stand-alone analysis.

For each country therefore, we again set out notable aspects of the policy and practice context that the stakeholders experience, provide brief illustrative quotations and associated discussion. The policy and practice contexts include the existence or lack of, in particular: state or commercial R&D support and activity; national mobility, heat and power supply policies and programmes; national mobility, heat and power supply infrastructure; and a range of other State and commercial activity. Stakeholders are very conscious of relevant activity outside of their country and frequently refer to this as well as to national factors. They also make a variety of observations and assumptions about the likely preferences and actions of other actors, particularly regulators, government generally, publics and companies.

5.1 Advanced hydrogen support

In this section the specific findings for the two countries, Germany and UK, which were categorized as countries giving higher levels of support to the development and diffusion of FCH technologies will be described.

5.1.1 Germany

In Germany, stakeholder views are influenced by the existence of the only dedicated national hydrogen implementation plan among the countries studied. Launched in 2006 with an expected lifetime of 10 years but extended to 2026, the “Nationales Innovationsprogramm Wasserstoff- und Brennstoffzellentechnologie – NIP” (National Hydrogen and Fuel Cells Innovation Program) is a public-private partnership across several ministries and regions, with an initial, planned budget of €700m from each of government and industry (€1.4bn total). NOW GmbH (National Organisation Hydrogen and Fuel Cell Technology) was created to manage this and is responsible for the coordination and management of the NIP and the “Nationaler Entwicklungsplan Elektromobilität – NEP” (National Electromobility Development Plan), launched in 2009. In addition, a 2014 National Action Plan on Energy Efficiency (NAPE) that focuses on the energy-efficient upgrade of buildings but also on the use of buildings and urban spaces. As a result, Germany has greatly expanded its district heating share of household heating.

German interviewees, operating in the context of a substantial, national-level hydrogen innovation programme, had their eye on the long term, where hydrogen technologies are viewed as a realistic prospect. For example:

> "Currently, it is a 'dry period' as it will take some time for the market to develop. This is different from the situation in other countries, e.g. in Japan, where much more of these appliances are already installed and running. And the Japanese manufacturers are now also entering the German market so that this may have a negative impact on German manufacturers as they are more developed." *Germany,* u*niversity research sector*

> „Of course, it's a shame, as a young technology it is still expensive and has no market advantages. Things will arise. Overall, regarding the assessment of the technology – stationary applications – I believe, that it is a very important new component, which will capture relevant market shares sooner or later." *Germany, government affiliation*

The survey results also underline Germany's role as a comparatively strong country on hydrogen issues. First of all, the Germans are to biggest sub-sample of the survey which to some extent is also due to the fact that there seems to be a larger hydrogen community. Respondents' expectations on market development correspond to overall average or are slightly more positive; expectations are highest for buses and storage and lowest for large-scale prime power. Like in most countries, costs are seen as the main challenge for all application types and safety as the smallest.

Regarding other stakeholder groups the perception of FCH-experts is that the familiarity of the public is lowest compared to other groups and familiarity is also perceived as relatively low for policy makers and regulators; it is evaluated as being highest for the research / the own sector. For both application categories under study, stationary and transport, public acceptance is regarded as medium. For transport applications the acceptance level for the public is perceived similar as for the automotive sector and politicians & regulators – in spite of high political and financial support compared to the other countries which are part of this study. Taking this together with the interview findings, this is likely to mirror the perception that FCH technologies are seen as (promising) future technologies and not as short term success.

5.1.2 UK

UK stakeholder views are influenced by the UK domestic heat context being one of largely natural gas-based, individualised heating provision: as of 2015, only c.10% of households had no boiler of their own. Until relatively recently, the UK had a strong commitment to encouraging renewable energy provision, including for heat, but the policy direction is currently less clear. The 2013 equivalent of a national heat strategy *The Future of Heating: Meeting the challenge* (DECC, 2013) made 42 references to hydrogen and took a whole systems perspective. However the consultative 2016 *Heat in Buildings* (DBEIS, 2016) has a much narrower scope, refers to district heating once and hydrogen not at all, and focuses largely on domestic boiler design. The UK is now viewed by the EU as falling behind on renewables targets and is less than half way towards meeting its target of supplying 12% of heat from renewable sources (REA, 2017).

The UK stakeholders were positive about hydrogen for different reasons. For example, a UK government ministry actor valued the potential for limited disruption of existing systems of heat provision. This actor's role led him to prioritise the minimisation of physical and hence political disturbance in connection with the public at large. He therefore emphasises the way in which hydrogen can be added to the existing gas grid with relative ease, acting as an alternative piped, district heat networks and requiring only, or at least primarily, modifications to existing equipment within homes (new or modified boilers for water heating and gas hobs for cooking):

> "If you compare that with hydrogen you are talking about someone coming in one day and changing the boiler for new boiler in much the same space, operates in much the same way as the previous one did… In terms of disruption that is hugely more attractive and a much easier sell than trying to convince people to take heat pumps."

> "Now if we are talking about heat networks the disruption there comes in terms of years of roads being dug up as heat networks to install and there is quite a concern about how practical that is going to be in London … "

Perhaps more notable in the UK than in other country contexts were regional differences. The UK is far from homogenous politically and economically and Scottish interviewees expressed positive beliefs about the economic opportunities of hydrogen and FCHs, particularly as a replacement for fossil fuel sector employment:

> "I think there are opportunities for the countries that lead on these technologies. We see Germany going for hydrogen in a big way. Scotland has also done that. We've got clusters in Aberdeen, Orkney, and Fife. We are placing ourselves well. There will be jobs created and opportunities for providing services and exporting as well. These are all opportunities that will come." *UK, private sector*

> "I think the energy sector, the people who install the hydrogen equipment, and people who design it, designers, installers and manufactures will have the most opportunities. It is the case that the electrolysers in our project are imported from Canada so we need to grow a UK supply sector as far as we can. There are opportunities for UK companies to grow their businesses." *UK, non-profit organisation*

Before interpreting the British survey findings it is important to note that this are based on the answers from 43, with the largest share (26 %) from educational organisations and a high share of respondents with few years of experience (44 % >5 years), the majority involved in policy development and program administration. Thus, the views from people from industry as well as from those who have a longer term experience in the field may be underrepresented.

Nevertheless, the expectations voiced about market development correspond to overall European average, with some indication that they are maybe slightly more positive for storage and prime power CHP; the most positive expectations are reported for buses and storage and the lowest for micro-CHP in homes – i.e. one of the applications studied in more detail in the questionnaire.

In line with the overall results, costs are seen as the main challenge for both, stationary and mobile applications, safety as the smallest. In additions, the infrastructure issue is mentioned prominently for transport. Familiarity of the public is regarded as lowest for both applications compared to other groups, public acceptance is perceived to be on a medium level; like in Germany for transport applications similar levels of acceptance are ascribed to the automotive sector and politicians and regulators.

To ensure anonymity of participating experts, they were not asked in the survey from UK area they come from. Thus, other than with the interviews it is not possible to extract regional differences.

5.2 Medium hydrogen support

Two countries, France and Spain, form the medium level category and the specific results for them will now be summarized.

5.2.1 France

There are no plans or programs supporting specifically hydrogen, fuel cells and their implementation in France. Stationary applications such as domestic CHP devices are not widely installed. Nonetheless there is widespread optimism for the future and positive experiences with light duty vehicles combining batteries with FCHs. The company Total, for example, is significantly engaged in projects involving hydrogen electrolysis for power to gas and fuelling for mobility. France hosts the Mobilité Hydrogène France initiative, which is a consortium raised as part of the Hydrogen Infrastructure for Transport (HIT) project, a European project financed by the TEN-T program, involving 4 countries. This is a strong and wide coalition which involves the French Government; energy companies; hydrogen and HRS producers; vehicle, fuel cell and electrolyser providers; research organisations; several regions and EU and French associations.

The French stakeholder interviews express considerable optimism – for example:

> "Hydrogen will play a tremendously relevant role in the future." *France, private sector*

> "Hydrogen technology will play a key role between green energies in France, as much as the others renewable energies, since it is a complementary solution." *France, public sector*

> "We need stronger environmental constraints for carbon market (as happens in Paris, for example, regarding the pollution of the city)." *France, public sector*

> "The most important thing to say about this subject is that a tendency has been established for the last 5 years and it must not stop.” *France, private sector*

French interviewees also expressed positive control beliefs in the sense of believing that FCHs would become ubiquitous – for example:

> "As this is a new technology, its costs are very high. Over time, these will decrease and it will become accessible to everyone.” France, public sector

That the French industry is an important player in advancing FCH technologies in this country seems to be mirrored already in the sample composition of the survey which includes a relatively high share of respondents from the private sector. The pattern of expectations on market development for FCH technologies and applications corresponds to the overall average, however, like in Germany, it is slightly above average.

Costs (both applications) and infrastructure (transport) are seen as the main challenges. For both application types, familiarity of the public is regarded as lowest and highest for the research sector. For stationary applications, acceptance from the public and policy makers acceptance is rated as medium and lowest in comparison to the other groups. For transport applications, acceptance is rated below the midpoint of the answering scale for the automotive sector and politicians and regulators.

5.2.2 Spain

Spain has neither national plans nor programs supporting specifically hydrogen and fuel cells. Hence for applications like CHP home appliances or devices, there are no specific mechanisms, plans or programs. Directive 2014/94/EU on the deployment of alternative fuels infrastructure drives the “Estrategia de Impulso del vehículo con energías alternativas (VEA) en España (2014-2020)” (Spanish Strategy to Foster the Alternative Energy Vehicle) launched by the by the Spanish Industry Ministry, whereby hydrogen is considered among other alternative fuels.

In general the Spanish interviewees were privately enthusiastic about the potential of FCH technologies and were strongly engaged in FCH development, yet at the same time they were frustrated at a lack of governmental support. Some examples illustrate this mixed experience: a *Spanish academic* with long experience with hydrogen and fuel cell research, who has recently been working on the production and storage of hydrogen via electrolysis with surplus electricity from a wind turbine array. The project is sponsored by the private company who owns the turbines, who are responding to regulated limits on their transmission of electricity to the grid, looking for other options for use of some the renewable power they generate. He says that his and other companies are experimenting with power to gas for strategic, learning reasons:

> “Some of the past experiences in Spain were a first approach from the companies to this technology, primarily to avoid getting left behind, because they saw that the competition in Germany or France was doing things, they just had heard about them”.

Yet he also describes the regulatory problems experienced:

> “Another problem is that there is no legislation. We had an experience in 2008 with a wind power company. We wanted to install a demonstration facility and we collided with the legislative barrier. You go to the corresponding council and the council looks away. The city council, the regional department or the ministry do not even know where to fit a project of these characteristics, because there is no legislative basis about these technologies ... it happens in all the applications of hydrogen. Try to convince the municipal administration or the municipal technical services to install a hydrogen refuelling station in the centre of a city. Very difficult.”

Some Spanish interviewees also emphasised the utility of hydrogen in roles other than as FC feedstock:

Instead, some expressed more confidence in non-fuel cell uses of hydrogen:

> "When we talk about hydrogen today, we always think about fuel cells. This is fine but there are still very few FCEVs, there is still no solution for heavy vehicles, etc. ... so then, we want to resume the tests done years ago to mix hydrogen and methane. You can propel a bus running on natural gas with a mixture of 20% hydrogen (you can reach even 25 to 26%) and the rest of natural gas.
>
> "The hydrogen field always seems to be in the skies, far away….but with this process [mixing hydrogen with methane in natural gas vehicles], we are not talking about the future. We have a lot of faith in this strategy.
>
> "At the end no one thinks that all cars will go with hydrogen, CNG may be an alternative, and at the end, I think it may be room for hydrogen and natural gas.” *Spain private sector*

The Spanish sample is the second largest subsample in the survey and it is also well balanced. Again, the patterns of expectations on market development are similar to other countries studied, but they tend to be more negative overall.

For stationary applications costs are seen as the main challenge and safety as the smallest. Familiarity of the public and policy makers is regarded as lowest compared to other societal groups and is perceived to be highest for the research sector. Regarding acceptance, it is rated below midpoint of scale and lowest in comparison for policy makers. For stationary applications, infrastructure, hydrogen production, awareness of regulators & politicians and costs come up as biggest challenges, safety as the smallest. Familiarity of the public is regarded as lowest compared to other groups and highest for the research sector. Acceptance is rated below the midpoint of the answering scale for the automotive sector and politicians and regulators and the public. Thus, overall the answering patterns in the survey correspond well with the finding from the interviews that experts from the FCH field are feeling more pessimistic compared to other countries and perceive a lack of governmental support.

5.3 Low hydrogen support

Slovenia is the only country in this study representing low hydrogen support and findings from this country are summarized below.

5.3.1 Slovenia

The Slovenian Government has no specific plans or strategies supporting hydrogen and fuel cells and its implementation. Some plans or documents at a national level consider hydrogen and fuel but with no specific plans or measures for its implementation. Slovenia has one hydrogen refuelling station in operation and another one under construction. For stationary applications like CHP, Slovenia has a developed market, primarily for district heating and industrial solutions. CHP is incentivized through a feed-in-tariff system. However no technology is preferred and fuel cell micro CHP plant are simply included in this support rather than receiving separate, additional support. Overall it was challenging to obtain meaningful interviews in Slovenia and this reflected the relatively low level of FCH activity nationally. The interviews revealed positive interest and commitment to FCH technologies, but the impression gained is that this was restricted to the specialist R & D community. For example:

> "Hydrogen technologies are efficient and green but rather complex." *Slovenia, university*

> "Hydrogen technologies are more environmentally acceptable than some others (e.g. Biofuels, bio-methane, etc.)". *Slovenia, private sector*

> "I estimate the role of this technology in Slovenia will be somewhat less than in the neighbouring countries (Austria, Germany etc), but much stronger that in the south-eastern parts. Let's say we will be at about 50% of the level achieved in Germany." *Slovenia, university*

The number of respondents from Slovenia was small in the survey, thus it is difficult to treat their answers as representing the country. However, the difficulties is involving people into the survey might already be connected to the fact that FCH technologies do not play a major role. In line with this and consistently., expectations on market development are more negative than other countries. Many of the answering patterns again follow those observed in other countries with costs being seen as major issue.

5.4 Evaluation of country grouping

Overall, relatively little and if so relatively small differences were found in the respondents' answering patterns if compared across countries. Thus, also the three types of support level for FCH technologies do not clearly emerge from the expert interview or survey data. Nevertheless, to some extent the empirical data still mirrors this categorisation with Germans, categorised as an advanced country, being comparatively positive and optimistic, although the difference is small in numbers. Similarly, Slovenian respondents representing a low level of support being comparatively negative. In addition to this, there might be a tendency that to some extent the quality of the samples obtained also has some relationship with the level of support, i.e. with higher quality samples in Germany and a very small one in Slovenia. But, as explained for Spain or the UK, within one and the same country stakeholders operate within sometimes contradictory structures, e.g. taking into account regional differences in the UK or seemingly a lower level of political support in France but maybe a higher one from the industry (although not perceived as such for transport).

6 Overall discussion

Comparison of survey and interviews

The survey and interview questions map only in general terms: the interview question design by necessity included fewer questions but invited a more open and extensive response. Furthermore, interviews elaborated questions from project-based perspective, while the survey took a more general view. Nonetheless some degree of comparison is possible and there are general commonalities among the qualitative and quantitative responses. Overall, across all countries and all applications, the survey respondents are very positive about FCHs: 88% respond that FCHs are a good or very good 'possible solution for energy and environmental challenges'. Buses, energy storage and back-up power systems receive the three highest mean ratings, with large scale systems for prime power or CHP receiving the lowest rating. German respondents were more optimistic than those of other countries and Spanish the least optimistic. The Spanish pessimism is also prevalent in the interviews.

The large majority agreed that governments and companies should support a transition to hydrogen technologies and they largely agreed that the sustainability of the way in which hydrogen is sourced will influence its public perception. Most of the survey respondents chose to answer specific questions about transport applications, rather than stationary applications – which is in line with the picture emerging from the interviews. The majority were positive about FCH vehicles relative to alternatives and about the use of public funding for specific purposes in relation to FCHs. Of the foregoing, the only somewhat substantive difference with the qualitative responses is a less equivocal overall evaluation: that is, the qualitative responses were more nuanced, conditional and specific regarding expectations of the future for FCHs, including relative to alternative vehicle types.

We also asked the survey respondents for their views of how others would perceive the technologies, based on the rationale that a successfully functioning innovation system requires an alignment of actors and functions (Hekkert and Negro, 2009). As with the interviews, the survey respondents are sceptical of the levels of support, familiarity and awareness that would be found among politicians and regulators; there is also some scepticism of commercial support.

General observations about the findings from the stakeholder studies

European energy policy is committed to increasing renewable energy supply, greenhouse gas reduction and increased energy efficiency (RED, 2009; COM(2010)639; COM(2011)112; EC, 2007; 2014). At issue here is what role FCHs will play in this process and – more particularly - what we can learn from R&D stakeholders at this point in time regarding the prospects for FCHs and regarding the actions that might be taken to improve these prospects. As set out in the Introduction, for the success of a particular technology, innovation systems and socio-technical transitions perspectives emphasise the importance of stakeholders being aligned in networks, with shared visions and expectations; channels and fora for knowledge sharing;

government policies for protection of technologies at an emergent or niche stage; entrepreneurial experimentation and market formation; and a generally supportive cultural landscape.

Considering the stakeholder responses in this light, we cannot yet infer that the innovation system for hydrogen and FCH technologies is strong across the range of countries considered. Neither would we be able to infer that there are strong signals that these technologies are yet breaking out of their niches into the mainstream 'regimes' of fuel supply and provision of mobility and heat and power. The environmental and technical potential of FCH technologies is strongly affirmed by most respondents, with the caveat that multiple energy conversion processes are to be avoided. However the obstacles to market uptake are also generally seen as profound in the short to medium term, with high cost and limited government and commercial support being seen as key problems along with regulatory issues not being resolved yet, as well as low perceived familiarity and weak perceived positive attitude among potential industrial/commercial users, politicians and regulators and the general public. Overall, this is not indicative of stakeholder alignment and shared visions.

However, it is notable that this perception varies across countries and is to some extent associated with differing levels of government investment in R&D programmes (Germany and Spain being apparently at opposite poles). There is also often localised enthusiasm. Moreover, there are some areas of commonality of vision: that FCHs, if used, they are likely to at first occupy particular niches; that hydrogen's value for renewable energy storage in electrical grid balancing and/or injection to the natural gas grid is of particular, potential value; as are the local air quality benefits, range extension benefits and uninterruptible power potential of FCHs. Moreover there is support for multi-sector networks, programmes and consortia, through which knowledge is to some extent shared. There remains, though, significant uncertainty among interviewees as to the ability of FCHs to compete with both mobile and stationary alternatives, given their relatively high cost and the lack of a hydrogen refuelling network. It is this cost that underlies the greater consensus on the value of hydrogen itself, for power balancing and gas grid injection, over the value of FCHs, except for specific possibilities (e.g. uninterruptible power, auxiliary power and high power demand such as fork lifts, heavy goods vehicles).

In terms of other innovation system functions, the direction of search by companies seems limited as regards FCHs: largely, commercial organisations are involved to the extent that there is State project funding. There is some entrepreneurial activity, but it is limited and interviewees often complained that engaging companies has not been easy. This follows from the perception and actuality of limited market development. Interviewees complained of limited regulatory support in this regard: market development generally requires appropriate institutional support and response, particularly in the case of a potentially hazardous fuel. However it would be difficult to make a strong case for limited market development being simply or largely attributable to inadequate regulation.

Niche processes and protection

Sociotechnical transitions perspectives direct attention to the role of niche processes, including competing, emergent technologies; the ways in which actors in the incumbent mobility, power and heat 'regimes' are responding to these; the different socio-technical 'trajectories' that are emerging and that may emerge; and the role of policy incentives including governance and network-building initiatives (e.g. in a mobility context, Geels et al 2011). In all of these regards, the stakeholder survey and interviews indicate that hydrogen and FCHs face considerable challenges and competition in the short to medium term, although some niche uses, notably FCHs for uninterruptible power, auxiliary power, heavy lift and also hydrogen as a means of storing and making use of excess renewable energy supply (including via injection to the natural gas grid) may have market potential in the near term.

For mobility, the interview and survey results indicate that vehicle manufacturers appear more supportive of other options (relative to FCHs) in at least the short to medium term, particularly hybrid and battery electric (BEV) options. Indeed for civilian mobility, FCHs might be said to still be at an experimental rather than niche stage, contrary to BEVs, which look likely to experience increasingly significant uptake, particularly where charging stations are available. Nonetheless, some stakeholders observe that the trend to electrification has the potential to assist FCHs by making electric powertrains and their supporting hard and soft infrastructures more prevalent. In this respect, the BEV form of electrification in transport, while in some senses competing with FCHs, as a pathway does avoid 'lock-out' by creating a regime structure that is consistent with FCHs (Geels, 2002, Kemp et al., 1998), while of course not being sufficient.

Sociotechnical theorists also highlight at least three ways in which niche technologies may be supported: 'shielding', 'nurturing' and 'empowerment' (Smith and Raven, 2012). Shielding involves the creation of a protected space, such as through fiscal incentives, procurement rules or public awareness campaigns. Nurturing aims to enhance learning opportunities and knowledge sharing, such as through network creation. Empowerment focuses on the ways in which a given innovation might breakthrough from the niche to the regime. Two different forms of this empowerment include 'Fit and conform', whereby a technology becomes competitive by reaching a stage of meeting the needs of the existing regime without on-going, special support. 'Stretch and transform' pathways denote the attaining of competitiveness by the innovation changing the regime itself (Smith and Raven, 2012).

Almost all interviewees called for one or more of the types of government support that sociotechnical theorists refer to above – indeed government support of one type or another was the dominant recommendation. Survey respondents agreed most strongly with the option of government funding for R&D and demonstration projects, closely followed by public facilitation of the installation of hydrogen refuelling points. Some also recognised the critical role of the cultural 'landscape', particularly prevailing values (priorities) vis a vis climate change. In this regard, there were significant differences in the perception of public attitudes by German and Spanish respondents. In general, though, the dominant message in terms of niche support measures was that FCHs are far from a stage of being able to survive unsupported and that without the installation of a hydrogen refuelling infrastructure, which is seen as far from a near-term prospect, in the transport sector they may not move beyond specific niches at all, despite their potential value.

Conclusions

This work package has investigated, qualitatively and quantitatively, the views of R&D stakeholders on hydrogen and hydrogen fuel cell applications, including perceived strengths, weaknesses, expectations and recommendations. The stakeholders questioned had a broad spread of backgrounds and consisted of 333 survey respondents and 145 interviewees from France, Germany, Spain, Slovenia and the United Kingdom, though with uneven country representation most likely reflecting differing levels of FCH R&D activity.

The aim has been to gain an informed understanding of the state of - and prospects for – societal acceptance of these technologies in five European countries. Societal acceptance is interpreted broadly, as involving not only publics but also other actors who have an influence on the success of technologies, including regulators, innovation agencies and companies. To this end, concepts from innovation systems and socio-technical transitions literatures have been used in the design and analysis of the study. Key among these is the proposition that successful societal acceptance of a technology requires a positive alignment of stakeholder views.

Overall, while the R&D stakeholders have a strong positive appraisal of FCH technologies, they perceive cost and limited regulatory, political and commercial support in addition to competition from other technologies as key, inter-related obstacles. Consequently, again despite the perceived benefits, stakeholders generally view these as likely to be realised in the medium to long term rather than near term. Many specific reasons are documented as underlying this, but chief among these are the cost of hydrogen refuelling infrastructures and FCH components, set in the context of automotive company commitment to battery electric vehicles and the lack of FCH cost-effectiveness for residential use. Nonetheless, FCH technologies are also perceived as offering some realistic niche potential in the shorter term, specifically uninterruptible power, auxiliary power and high power demand such as buses, fork lifts and heavy goods vehicles. Similarly renewable hydrogen is viewed as offering near term potential for storage of renewable energy power for grid balancing and also for injection to the natural gas grid.

7 Conclusions and policy recommendations

Based on the objectives specified in the research design, we have examined a number of key issues with regard to the stakeholder acceptance of hydrogen supply and use, mobile and stationary FCH technologies. From this, it has been possible to examine the strengths and weaknesses of the innovation systems for FCH technologies and particularly in terms of what stakeholders think needs to change for FCH technologies to advance. Concluding from findings they suggest that:

1. **A majority of stakeholders consider that FCH technologies are positive for the environment**

Interviewees highlighted the potential of hydrogen technologies to reduce pollution and combat climate change. This aspect is especially important in the application of FCEVs in order to reduce air pollution in cities. Furthermore the potential role of hydrogen for renewable energy storage in electrical grid balancing is perceived as important as it can promote the expansion of renewable energies.

The global commitment to protect the environment is perceived as a key advantage for hydrogen applications in comparison to fossil alternatives.

2. **FCHs are perceived as mature technologies**

According to the stakeholders interviewed and surveyed, FCH technologies are good per se and an efficient alternative to existing technologies. For example, in H2 and non-specified or dual use, interviewees consider that it is a good medium for other energy sources and a vector for heat and power. In the case of stationary applications, hydrogen technologies provide uninterruptible power and UK stakeholders, for example, highlight that these can be integrated with existing technologies and have high power opportunities. When discussing about FCEVs, stakeholders report technical advantages related to the operational performance (quick refill, torque, rapid cool down or cold resistant), and generally, the strong performance of those application. With regard to refuelling stations for cars, some stakeholders perceive that there are still some technical challenges to be met.

The survey revealed that stakeholders' expectations are more positive for H2-buses and H2 as a means of storage for renewable energy, followed by H2-based back-up power systems. Least positive prospects are seen for large scale systems for prime power.

3. **From scepticism to expectance: social perception of FCH technologies**

Generally, stakeholders think that FCH technologies are perceived positively by the general public and key actors. As mentioned by interviewees, despite previous social concerns such as safety, they perceive that users tend to accept and ask for new technologies. According to the stakeholders, new FCEV users are satisfied with the technology.

Table 9 Main advantages, disadvantages, recommendations and expectations, as reported by the stakeholders for the three applications.

Application	Strengths (from most important to less important)	Weaknesses (from most important to less important)	Recommendations	Expectations
H2 and non-specified or dual use	• Environmentally positive (DE, ES, UK, FR, SI) • Storage medium for other energy sources & electrical DEid (DE, ES, UK, FR, SL) • A vector for heat and power (DE, ES, SL) • Positive societal evaluation (FR, DE) • Affordable (UK, ES, SI)	• Lack of markets / markets acceptance (ES, UK, SL, FR, DE) • Financial cost (ES, UK, SL, FR,DE) • Inadequate or excessive regulations/ standards (DE, ES, FR, UK) • Scarcity of H2 supply (SL) • Handling and transport of H2 (SL)	• Governmental and political support (DE, ES, UK, FR) • Fiscal support (DE, SL) • Inform and engage all stakeholders (ES, FR) • Power to gas (ES) • R&D to reduce cost (DE) • Commercial partner support (UK) • Strategic targeted support (SL) • Regulatory support (UK)	• Generally positive (DE, SP, UK, SL, FR, ES) • Market development in near term (DE, FR, UK) • Strong potential, uncertain future (ES, UK, FR) • Power to gas (DE, ES, FR) • Automobile use critical to H2FC future (ES, FR) • Widely prevalent in the long term (SL, UK, ES) • National differences and specificities (FR, UK, ES)
Stationary applications	• Uninterruptible or portable power (FR, UK, ES, DE) • Reliability (DE, UK, ES) • Efficiency (DE, ES, SL) • Positive perceptions (DE, FR) • Environmentally positive (DE, UK) • InteDEation with existing infrastructure (UK) • High power opportunities (UK) • Reduces disruption for consumers (UK, SL) • Reduces pressure on electrical supply network (SL, UK) • Suitable for various special conditions (SL, DE)	• Financial cost (DE, ES, UK, SL) • Limited awareness and support by government/regulator s (DE, UK, SI, ES) • Underinvestment (FR, ES) • Relatively low power (FR) • Challenge of finding commercial partners (SL, DE, ES) • Supply and distribution problems (UK, DE) • Competition from alternative technologies (UK, DE) • Complexity of the system and/or its components (ES, SL) • Inefficiency (ES, DE)	• Sustained government support in general (FR, SL, DE, ES, UK) • Enhance public awareness and understanding (UK, DE) • R&D to reduce relative cost (FR, DE) • Regulatory support inc. re safety (SL, UK, DE) • Coherent government support (UK) • Commercial partner support (ES) • Policy incentives for storage (ES)	• Generally positive (DE, UK, FR, UK, ES) • Market development in 5-10 years' time (near-term) (FR, UK, DE, ES) • Negative (SI) • Low expectations in short to medium term (ES, SL) • Government support (DE) • Uninterruptible supply systems as a niche (DE) • Inevitability / sooner or later / enthusiasm (UK) • H2 as a storage is key (UK, DE) • Niche uses first (FR, UK)

Application	Strengths (from most important to less important)	Weaknesses (from most important to less important)	Recommendations	Expectations
Transport applications	• Technology good per se & relative to alternatives (FR, UK, DE, ES) • Lack of local /other emissions (FE, SL, UK, ES) • Range, quick refill, torque, rapid cool down, cold resistant (FR,DE, ES, UK) • Safe and silent (SL, FR, UK, DE) • Suitable for specific fleets (SL) • Efficiency of fuel cells (SL) • Strong performance and support generally (UK) • Hydrogen as a co-gas with CNG for vehicles (ES)	• Financial cost (ES, DE, UK, SL, FR) • Competition/perceived competition with other tech. (ES, UK, SL, DE) • Limited awareness and support by regulators/governmen t (all countries) • Lack of (sustainable) hydrogen supply (FR) • Complexity of the technological/socio-technical system (all countries • Lack of markets (all countries) • Lack of public awareness (FR)	• Governmental and political support (FR, SL, UK, DE, ES) • General support to reduce relative cost (SL, UK, DE,ES, FR) • Investment in refuelling infrastructure (UK, ES, DE, SI, FR) • More communication and engagement generally (FR, UK, ES) • Inform and engage people/publics (FR, UK, DE, ES) • Regulatory support including re safety (SL, FR, UK, DE) • R&D to reduce cost generally (DE) • City level support (DE, ES)	• Generally positive (ES, DE, UK, FR, SI) • Low expectations in short to medium term (ES, DE, SL, FR, UK) • Corporate and market differentiation (DE, ES) • Tighter emissions standards will drive H2 in transport (UK, FR, DE) • Modest development relative to other countries (SL) • Inevitability and incontrovertibly valuable (SL) • Specific vehicle types first (SL)

4. Financial cost is perceived as the main weakness

Economic issues are pointed out as one of the main obstacles for the development and commercialization of hydrogen technologies. Interviewees in line with survey respondents generally refer to barriers such as:

- High cost and lack of competitiveness of hydrogen production and storage.
- Lack of infrastructure installations / facilities (for example, refuelling stations) and high costs for developing the infrastructure.
- Final price for consumers/users is very expensive (in private vehicles for middle-class user and bus fleets for public administration as well as stationary applications for private households, it is an extra cost not affordable for a new technology)
- Associated costs of hydrogen technology are high. Moreover, in some countries, the lack of markets and the absence of economies of scale difficult the initial development.

5. Inadequate/ excessive regulations – limited awareness by government:

According to interviewees, specific legislation for renewable energy generation, production and management that favours the use of hydrogen is non-existent, inadequate or excessive in some countries (this is perceived as a critical issue in the Spanish context). This is in line with the results of the surveys: stakeholders perceive that politicians and regulators have a limited awareness of FCH technologies.

6. Stakeholder still claim more general support

A common recommendation made by stakeholders is the need of a solid strategy and specific policies to promote hydrogen technologies. Some stakeholders emphasize that each country has different objectives and a common European strategy would be paramount. Stakeholders claim for more commitment from government and politics to encourage the development of hydrogen technologies via policy incentives, regulatory support or investment in R&D to reduce cost. Also, a general perception is the requirement of strong commercial partnerships.

7. Communication and engagement are a precondition

In order to achieve public acceptance, stakeholders highlight the need to inform and explain hydrogen applications. The survey indicated that the public is perceived as the group with the lowest level of awareness, followed by politicians and industrial/commercial users. According to the stakeholders, it is important to communicate the benefits and safety issues to get public awareness.

8. Different expectations on different applications

Ambivalent feelings are reported by interviewees when asked about the future of the hydrogen sector. In general, they tend to have positive views, and consider that the market will develop in near term (5 years). But expectations vary between applications. Interviewee's view of hydrogen supply and use are positive and they consider hydrogen will play a key role in green energies. They also think there are economic opportunities for hydrogen technologies as storage medium.

Regarding stationary applications, Spanish interviewees have the worst expectations. They consider unlikely that residential fuel cells will develop in the medium term. They perceive the market is not developed and demand will be very low. Others interviewees mention differences between countries, for example, the developed Japanese market, where there is a strong support by the government. Also some interviews perceive that residential fuel cells cannot compete with alternatives, for example, cogeneration or solar thermal technologies.

There are also divided expectations in relation with FCEV. There is a generally more positive feeling about the future of fuel cell vehicles, although also expectations are low in the short to medium terms.

Policy recommendations

The aim has been to gain an informed understanding of the state of - and prospects for – societal acceptance of these technologies in five European countries. Societal acceptance is interpreted broadly, as involving not only publics but also other actors who have an influence on the success of technologies, including regulators, innovation agencies and companies. To this end, concepts from innovation systems and socio-technical transitions literatures have been used in the design and analysis of the study. Key among these is the proposition that successful societal acceptance of a technology requires a positive alignment of stakeholder views.

Overall, while the R&D stakeholders have a strong positive appraisal of FCH technologies, they perceive cost and limited regulatory, political and commercial support in addition to competition from other technologies as key, inter-related obstacles. Consequently, again despite the perceived benefits, stakeholders generally view these as likely to be realised in the medium to long term rather than near term. Many specific reasons are documented as underlying this, but chief among these are the cost of hydrogen refuelling infrastructures and FCH components, set in the context of automotive company commitment to battery electric vehicles and the lack of FCH cost-effectiveness for residential use. Nonetheless, FCH technologies are also perceived as offering some realistic niche potential in the shorter term, specifically uninterruptible power, auxiliary power and high power demand such as buses, fork lifts and heavy goods vehicles. Similarly renewable hydrogen is viewed as offering near term potential for storage of renewable energy power for grid balancing and also for injection to the natural gas grid.

Based on these findings and in order to promote the adoption of hydrogen and fuel cell applications, we suggest that:

- There is a need for more sustained and coherent Government (including European-level) support. Furthermore more regulatory support is needed, in particular relating to issues of safety. Air quality regulations to restrict the use of fossil fuels for heating and generating electricity were identified as one of the key factors for the future market development of stationary applications by the stakeholders and thus should be implemented if not yet in place. In addition the stakeholders recommended support leading to cost reductions.
- The installation of hydrogen refuelling stations is a key precondition for the diffusion of FCEV. Not only the lack or refuelling stations but also the reliability of the technology is an issue. Funding of research and development projects is important to make the FCEV technology and the related infrastructure more reliable and the reduce the relative cost of the technology.
- Green hydrogen was mentioned as important in the context of social acceptance of hydrogen. Projects should be funded which demonstrate the capability of the on-site hydrogen production from renewable energy technologies, like wind energy or photovoltaics. These clean energy technologies should be promoted as the preferred source of hydrogen production. These projects can create public and local support for hydrogen technologies.
- The stakeholders believe that familiarity with FCEV is low in the public, but also among politicians and regulators. Thus there is a need for further demonstration projects and communication campaigns to increase public awareness and support for hydrogen technologies and inform and engage all stakeholders.

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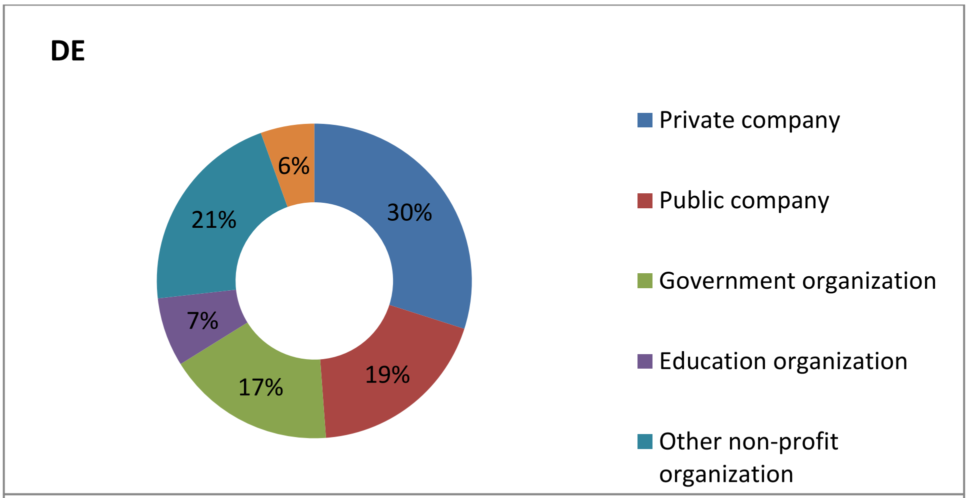
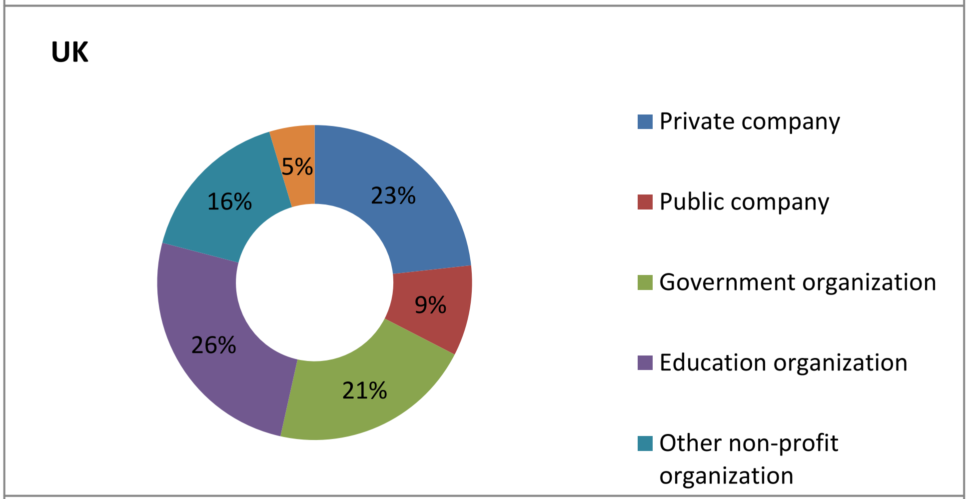
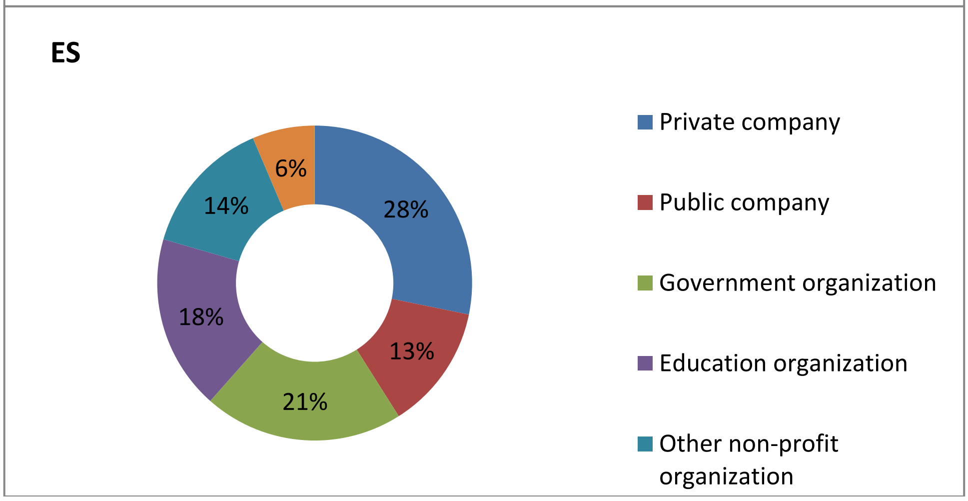
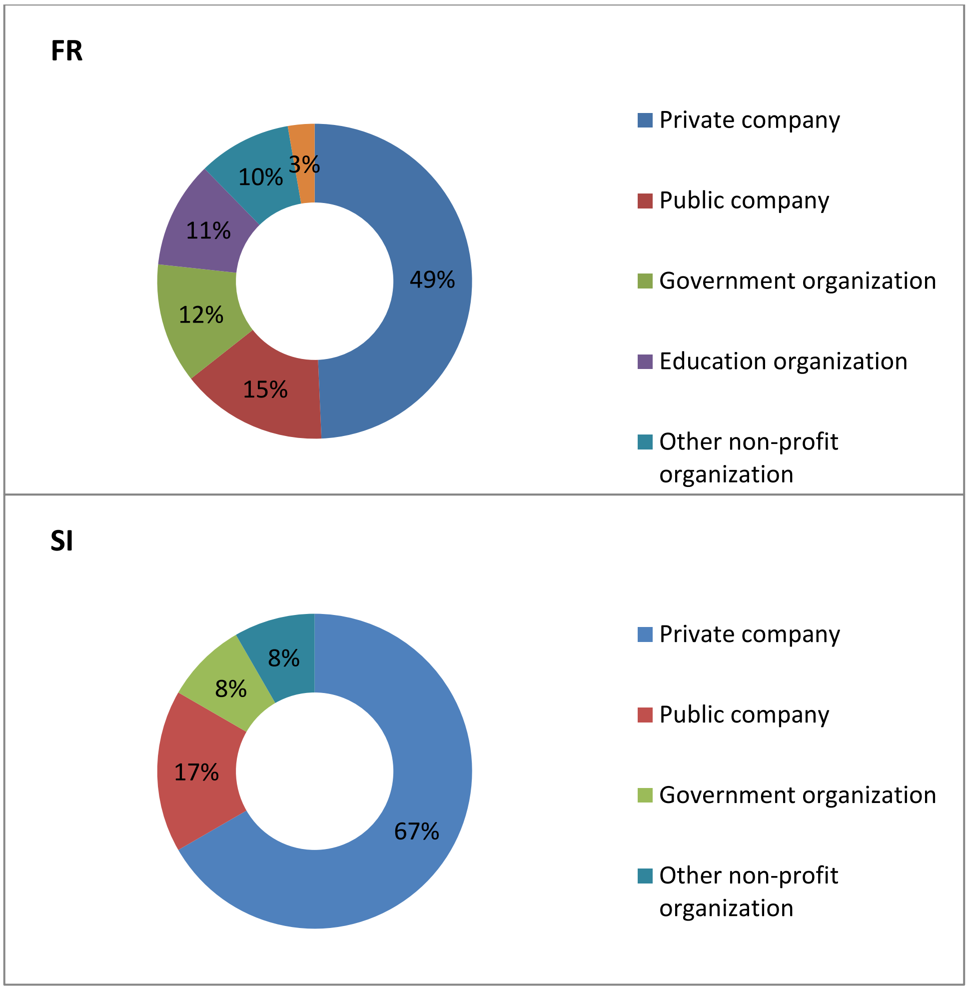
9 Appendix 1– additional figures from stakeholder survey









FigureAnnex 1 Organisational affiliation of stakeholders per country

	Frequency	%	DE	UK	ES	FR	SI
I am not directly involved	60	18	17,3	20,9	10,3	21,9	41,7
Less than 5 years	88	26,4	25,2	44,2	19,2	23,3	41,7
Between 5 and 10 years	71	21,3	22	23,3	16,7	26	8,3
Between 11 and 20 years	90	27	26	7	46,2	24,7	0
More than 20 years	24	7,2	9,4	4,7	7,7	4,1	8,3
Overall	333	100					

FigureAnnex 2 Respondents' years of experience with FCH technologies

10 Appendix 2– additional stakeholder quotations

This appendix contains additional interviewee comments that to some extent duplicate those included and hence are excluded from the main text for reasons of brevity.

Hydrogen supply and use strengths

> "This technology will allow us to not depend exclusively on other energies."
>
> "The advantage is that fuel cells are more efficient, and that they can generate heat and electricity at the same time...".
>
> "The Technology is clean and silent; it can significantly reduce the pollution levels of greenhouse gases and noise."
>
> "The advantage of cells compared to turbine or to the engine is the absence of noise and of vibrations. Cells are stationary elements. In an urban environment it is very important. In highly populated areas of the world it may be an alternative."

Positivity

> "I think people that have an interest in hydrogen are very, very positive, very forward thinking. They are absolutely driven by their belief that it will work and I think that’s absolutely right."

Hydrogen supply and use weaknesses

Cost

> "We were interested in terms of experimentation. The technology was more in vogue at that times, but in times of economic crisis, it seems to be an expensive process and does not attract investment.”
>
> "Electrolysis is too expensive, it is necessary to reduce its costs.”
>
> "One of the challenges that you then run into is purity of hydrogen that’s going down the pipes. The purer you make you hydrogen the more expensive it is to produce but typically at the moment most hydrogen fuel cells require a very high quality fuel. So there is compromise to be had there."
>
> "It has intrinsic advantage, especially low pollution, low emission of pollutants, but in return it costs a lot of money and has a lifespan relatively low, so you must spend more money in a few years. Therefore, when a decision-maker chooses it, in fact he magnifies the environmental benefits, perhaps for a particular policy interest.”

"It is not a cheap energy. It is cheaper to generate electricity with natural gas but there are other ways even cheaper: wind and hydraulic power."

"We are not experts but investments in this type of systems to store wind energy may actually slow down. Because maybe it is much cheaper to manage the electricity network than to store electricity."

Safety

"The fear of people towards this type of technology is the result of a lack of information on both its benefits and the affectivity of the security procedures established for its use."

Regulation

"Another big problem, apart from the technical impediments, was the administrative. The processing in Spain, unfortunately, there's no really a favorable environment for research and pilot projects. They treated us as being cogeneration or even an explosive plant because we had a hydrogen plant. The regulation was more stringent than for any gas station…. Environmental legislation, but also administrative, electrical, mechanical is a big problem..."

Lack of Government strategy: Spain

"The second weakness we have is the absence of a national strategy. For me it is a big disadvantage. We do not have a national strategy on hydrogen and fuel cells. It does not exist. Is there any financing from the government, any kind of subsidies? If there is no strategy, there is nothing."

"Last year in Spain hydrogen appeared in the draft of the Royal Decree (the last in November) with other fuels. However, when the RD was published in December, hydrogen had disappeared. A very strange thing. They have not given us a explanation ... In the last draft hydrogen appeared, and suddenly, it passed by the Council of Ministers and in the publication of the BOE, hydrogen had disappeared. You can make yourself an idea of the spirit…"

"The European Law promoting the development of the infrastructures for alternative fuels was approved at the end of 2014 and European countries are trying to implement it until the end of 2016. Among the alternative fuels it was the hydrogen, unfortunately as an option. According to me, this is discrimination. (…) Because it is an option and some countries have not showed interest on hydrogen and they have removed in the transposition."

"If we still discriminating this technology (hydrogen), it will not be an option, never".

Awareness of hype cycles

"In the end we all…know well where we are nowadays. The thing is that there was a time in which we all thought hydrogen will be really the future."

"I started working with hydrogen in 2000. On that moment, it seemed that hydrogen would be the solution for everything; everybody said it was great, that it will have a brilliant future…".

"This [FCHs] suffers from cycles that are out of phase with electric batteries. I remember when the batteries were worthless and fuel cells were perceived as the best option. Now it's the opposite. I do not trust that. My message to the people working on fuel cells is that this is up to them. I would love that this technology moves forward. And I think it depends on the scientific community really believing in it and getting over the existing challenges. And then you need the support of regulators."

Storage as key

"I think the key will be getting cheaper and safer systems for hydrogen storage. Technically the fuel cell is a good choice. For the cost out it is a matter of market volume. But we need a system of cheap and easy storage."

Hydrogen as playing a key role in future

"I am sure hydrogen will enter the market, of course, absolutely sure. It will take more or less time but it will come out, the logic is this."

Communication and engagement

"We need more demonstration projects involving regions and local communities."

"It's crucial to work on a common message to users about the benefits of hydrogen and the positive impact that it would have on the future."

"We need to know each other. We have to talk; the scientific community, the industry, the local and public authorities to see that we can do, where we have to start and to work with a plan or a framework. We need clear objectives."

Power to gas

"For example, Germany has no choice. Because Germany cheats at us, everyone here is cheating at us. Germany planned the closure of nuclear power plants, but for maintaining the system stability it is necessary resorting to combined cycle plants. The next wave of social pressure will demand the closure of coal plants, if this occurs, Germany will end up without electricity. So, if you substitute nuclear energy for gas, you are increasing CO2 emissions. But the countries have the commitment to abate CO2. And the only way to abate CO2 is using the power to gas, for this reason they are promoting it".

Strategy and policy

"It is very easy, we need a strategy. You need an alignment of all the stakeholders to a point. If you align all stakeholders in one direction, everything else is given. You do not need billions, you just need to say; "Gentlemen, we are able to migrate from a current energy paradigm [...] towards an energy paradigm in which we produce the hydrogen, the fuel cells, we use electricity and hydrogen as energy carriers changing from one to another. [...] You say, that's what the companies have to do, that's what you have to do in the research area, that's what you have to do in the government. [...] Then people start to be aware of hydrogen and fuel cells, journalists become interested in it and write about it, then you are closing the circle."

Stationary applications: Perceived weaknesses

Lack of interest nationally

"We abandoned the research for a combination of reasons…The transfer from research to the market does not work well in Spain. We had a better polymer, which would allow PEM fuel cells technology at high temperatures ... which means technical advantages and engineering. But you go with your product and the companies tell you, ok, but we will continue to make stacks with the elements we have ... in Spain, there are no materials manufacturing companies ... I cannot do anything. I only have one element of a clock, but I cannot sell watches...the solution would have been to have Samsung instead of a Spanish company.”

"At the research level, in Spain we are in a good situation. When I go to international conferences I realize we have a good level, similar to the others. But we are in a worst situation in terms of transfer, it lacks companies wanting to do it and taking advantage of the "know-how" we have."

Cost

"One of the problems is the low efficiency, in the entire process from the collection to the use. If your start with the electricity generated by a photovoltaic panel to the electricity supplied to the vehicle, the efficiency is 30% efficiency; you have to generate the hydrogen, transport it, load it, provide it and use it. While lithium batteries allow efficiencies of around 90, 95%. So from a global point of view, the level of efficiency has to be taken into account".

Stationary applications: expectations

"Research on fuel cells for domestic uses in Europe is increasingly residual. Maybe is similar to the situation of lithium ion batteries in 2005, that was almost stopped because a solution was not seen. It was thought that they would not evolve any more."

"At the end, if electric batteries begin to develop I see it as much more feasible to install panels at home than fuel cells, really".

"Domestic (private) cogeneration is impossible… Who is going to manage it? Cogeneration in shared buildings (neighboring communities) is really another issue. It involves giving up a parking space but it is not too much. From the point of view of the management of the grid, there is a problem of control, it is difficult to manage, a mess. I do not see it really possible…".

"Injecting hydrogen into the network I see it very feasible, very possible and relatively close, but fuel cells at homes I cannot see it ....".

Mobile applications: weaknesses

Competition with alternatives

"The problem is that there are no hydrogen refuel stations. There is an European directive on alternative fuels, defined two years ago, and it has to be implemented in Europe."

"Only Hyundai and Toyota and Honda ITX sell commercial vehicles now, but their commercial projects sales do not consider Spain. Imagine you're a hero and want to refuel in the 4 hydrogen stations in Spain, and you want to buy a Mirai, unfortunately, you cannot. You have to go to Germany and import it. That is what CNH2 (Spanish Hydrogen National Centre) are trying to make, they are planning to install a refueling station and they will try to buy a vehicle, but you cannot buy it in Spain…. If there are not refuel stations and the two companies do not sell their vehicles… They do not have business plan sales because it includes having technicians, a sales network and so on ... They are not going to spend on something that the government of the country does not bet."

Lack of infrastructure

"You need to distribute a new gas…Hydrogen has the problem of the pipelines, they are very expensive to build."

"The problem I think is the need of public investment to put hydrogen everywhere ... there were also problems with the production of hydrogen, but regardless of production, the key is having the infrastructure and I don't think governments are going to spend millions of euros in such an infrastructure."

Safety

"Nowadays, consumers do not have much interest in this technology because they consider it dangerous and very expensive."

Costs

"People are working on cheaper catalysts. The problem seems to be the stability; they do not seem to work for many hours. It seems to be far from being able to work in the field. That is the first challenge. To find improved and cheaper fuel cells, without platinum. I know there are fuel cells without platinum, but because they work at another temperature. But the problem is, would you buy a car that you need to heat your battery to 700 degrees to start working? Also, how do you do it?"

Expectations

"At a conference I thought: if a Martian came down will thought that there is still a long time for hydrogen fuel cells to be available in the automotive industry."

"While the big actors of the automobile industry keep on not betting "seriously" on H2, its future application will keep being very limited."

"As we sit here today with fewer refuelling stations than I have fingers on one hand it's not feeling like were on a cliff edge and we're just about to see a major launch."

"There is another niche that is interesting in a medium term: the application of hydrogen in heavy vehicles (trucks, buses, heavy tonnage…). It would be fleets driving with a specific route and it would be possible to refuel in superhighways, in some European countries they are building the minimum infrastructure. (…) European Law of Renewable Energies considers the creation of this type of "green" highway corridors in which it would be easy to refuel with hydrogen".

"It's been a success. We've got 10 vehicles running in Aberdeen, which have done the most kilometres, carried the most passengers, and we have the most effective refueling station in Europe. The interest in hydrogen and fuel cells within Scotland ensures a significant investment in hydrogen from Public and private sector partners, including the Scottish Government and other local authorities."

"We're going to start with hydrogen-methane mixture. We are using a vehicle technology quite mature, known and safe, without technical risk I mean, and we will start testing with hydrogen; to see where we can produce the hydrogen, to see how we compress it…

"There is no problem in using hydrogen in an internal combustion engine.

"You can feed an engine with hydrogen alone; the problem is that it gives you half the power because it has a very low heating value. But If the engine was 300 hp in natural gas, will continue to give 300 hp with a mixture of 20-25% hydrogen."

"With the mixture of hydrogen and methane we are not talking about processes in the laboratory, because X already has accumulated experience of NG vehicles ...running with this mixture and they work perfectly. It is a mature technology. So our approach is, we will not discuss about the fuel cell. Ok, it is a wonderful technology. But it is not going to happen tomorrow. It is going to take some years."

Large players as key

"... for the FCH, several automobile companies have had to ally, to bear the cost that FCH has today. There are very few companies as large as the automobile industry ... medium, small companies are reluctant to make investments, they are waiting how the industry evolves”.

Conditional on battery improvements

"The refueling time for an electric vehicle is excessive. In the United States it makes sense because they can park their car at home and leave it charging overnight. But very few people in Spain have a house with a garage where you can charge the car."

"As long as the EV does not solve the long refueling time, it is very difficult for it to be widely adopted."

Auxhiliary power

"What they have to do to contribute to commercial flights is that electric consumptions on board, will be powered by other generators such as fuel cell".

Recommendations

View alternatives as complementary

"Particular vehicles will be hybrids. One generation will have battery and the other fuel cell. This vehicle will have a market quote: for short distances, maximum of 200km, and fuel cell do not have to compete, it will be battery vehicle."