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THE PUBLIC ACCEPTANCE OF HYDROGEN FUEL CELL APPLICATIONS IN EUROPE

LA ACEPTACIÓN PÚBLICA DE LAS APLICACIONES DE LAS PILAS DE COMBUSTIBLE DE HIDRÓGENO EN EUROPA

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Abstract

There is increasing realisation amongst policy makers and industry that 'social acceptance' is a key issue in the deployment of low carbon energy technologies and infrastructures in Europe. The development of hydrogen fuel cell technologies (HFCs) involves small-scale residential and transport applications, as well as large-scale infrastructures, the socio-technical embedment of which will be influenced by the public and stakeholders in various roles. Previous research on public acceptance has investigated public perceptions of HFCs in specific countries.

Resumen

Cada vez hay más conciencia entre los responsables políticos y la industria de que la "aceptación social" es un tema clave en el despliegue de tecnologías e infraestructuras energéticas de baja emisión de carbono en Europa. El desarrollo de las tecnologías de pilas de combustible de hidrógeno (HFC) implica aplicaciones a pequeña escala en el sector residencial y del transporte, así como infraestructuras de gran escala, cuya incorporación sociotécnica estará influenciada por el público y las partes interesadas. Investigaciones anteriores sobre la aceptación

Here we present survey data on a multi-country scale, using a multivariate, socio-psychological approach. We particularly focus on cross-country differences in self-reported awareness and familiarity, global attitude and support in relation to mobile and residential HFC applications. Our data shows that less than half of the population in the seven countries are aware of the existence of hydrogen and fuel cell technologies in the context of energy production. The level of familiarity with both applications is low, and less than 10% of respondents consider themselves familiar with these applications. In general, respondents in the seven countries have a positive initial attitude towards HFC technologies and are likely to accept and support the adoption of residential fuel cells and HFCEVs. The seven populations studied are similar in their attitudes towards HFC technologies, but there are small to moderate differences in awareness and acceptance of HFC applications across countries. We finally found that positive and negative affect, perceived benefits, preference for alternative technologies, trust, and age were significant correlates of acceptance of HFC applications. We consider the implications of these differences for the public acceptance of HFCs.

Keywords
Attitudes; Energy technologies; Survey.

pública han trabajado sobre las percepciones públicas de las HFC en países específicos. Aquí presentamos datos de encuesta a escala multinacional, utilizando un enfoque socio-psicológico multivariado. Nos centramos particularmente en las diferencias entre países en cuanto al autoconocimiento y familiaridad, la actitud global y el apoyo en relación con las aplicaciones de HFC móviles y residenciales. Nuestros datos muestran que menos de la mitad de la población en los siete países son conscientes de la existencia de tecnologías de hidrógeno y pilas de combustible en el contexto de la producción de energía. El nivel de familiaridad con ambas aplicaciones es bajo, y menos del 10% de los encuestados se consideran familiarizados con estas aplicaciones. En general, los encuestados de los siete países tienen una actitud inicial positiva hacia las tecnologías HFC y es probable que acepten y apoyen la adopción de pilas de combustible residenciales y HFCEVs. Las siete poblaciones estudiadas son similares en sus actitudes hacia las tecnologías de HFC, pero hay pequeñas diferencias en la conciencia y aceptación de las aplicaciones de HFC entre países. Finalmente encontramos que el efecto positivo y negativo, los beneficios percibidos, la preferencia por las tecnologías alternativas, la confianza y la edad tienen una correlación significativa con la aceptación de las aplicaciones de HFC. Consideramos las implicaciones de estas diferencias para la aceptación pública de las HFC.

Palabras Clave
Actitudes; Encuesta; Tecnologías energéticas.

Introduction

Among the alternative technologies for generating low-carbon heat and electricity and replacing fossil-fuel based powertrains, residential fuel cells and hydrogen fuel cell electric vehicles (FCEVs) are receiving support towards commercialization. Home fuel cells offer some important benefits over other low-carbon heating technologies, and cost reductions and financing mechanisms for the purchase or installation are bringing the technology close to commercialisation in several countries (Dodds et al., 2015; Ammermann et al,. 2015). Although the technology will likely remain comparatively expensive, it is assumed that home fuel cells have mass-market potential and will have a significant impact on reducing emissions and primary energy consumption where they are deployed (Ammermann et al., 2015). The deployment of FCEV, although still facing several challenges, is advancing worldwide; fuelling infrastructures are being set up in several countries and auto manufacturer actions seem to confirm their commitment to keeping fuel cell technology as an option (Eberle, Müller, & von Helmolt, 2012; Air Resources Board, 2015).

Public and consumer acceptance will likely play a role in the successful adoption of hydrogen and fuel cell applications, both in the residential and the transportation sector. The future is uncertain: HFC applications may benefit from a public willingness to take up more efficient heating and transport systems, or the public may prefer other alternatives or even incumbent, fossil fuel or combustion-based technologies that might be perceived as safer, cheaper, more effective and easier to control (Dodds et al., 2015). As markets for hydrogen and fuel cell technologies develop, citizens may react in different ways to energy policies and local infrastructures deployed in their countries, regions and cities, and end-users will decide whether fuel cells fit their particular circumstances. Similar to other energy technologies, HFCs will likely face different levels of social and public acceptance in different countries.

To help understand public reactions to HFC technologies, a large body of research on public attitudes towards hydrogen and fuel cell technologies has developed in the last ten years. Generally, the available studies indicate that low levels of knowledge of - and interest in – FCH technologies coexist with relatively high levels of acceptance and support (Achterberg et al. 2010). Also, they suggest that public attitudes towards HFC technologies might vary depending on the type of application considered. However, this research has generally focused on specific countries or regions and there are very few cross-country studies systematically comparing public attitudes to HFC applications.

In this paper, we analyse public attitudes towards residential fuel cells and hydrogen fuel cell electric vehicles (FCEVs). Both applications of hydrogen and fuel cells were selected given their potential effects on primary energy consumption and their mass-market potential. This analysis is based on survey data collected from a representative sample of residents in seven European countries with different levels of market penetration and government support and examines the differences in awareness, global attitude and acceptance of home fuel cells and hydrogen fuel cell electric vehicles. We begin with an overview of the literature on public opinion and understanding of hydrogen technologies.

Social research on public acceptance of hydrogen and fuel cell technologies

Public attitudes towards hydrogen and fuel cell technologies have received significant attention from the social sciences in the last 20 years. Available studies in different countries have examined public awareness, understanding and acceptance of hydrogen and fuel cell technologies, as well as the factors that predict support and opposition. This research includes different research designs, studied populations (general public, users, population affected by hydrogen infrastructures, selected age groups, students, and workers) and hydrogen and fuel cell applications. An overview of the various conceptual frameworks and methodologies used in this research has been provided in various review articles (Ricci, Bellaby, and Flynn 2008; Truett, Schmoyer and Cooper 2008; Yetano Roche et al. 2010). In order to facilitate the discussion of the results, we classify the studies reviewed in this section according to the type of application under study: hydrogen and fuel cells technologies in general, vehicles and home applications.

Hydrogen and fuel cell technologies

A significant proportion of the studies on public attitudes and acceptance of hydrogen and fuel cell technologies has examined the levels of public awareness, familiarity and understanding of HFC technologies in general, as well as public support for government investment in hydrogen; however, as mentioned, this has generally been undertaken in individual countries. Such survey studies at the country level with representative samples of members of the general public have been carried out by Zimmer & Welke (2012) in Germany; Zachariah-Wolff and Hemmes (2006) or Achterberg (2014) in the Netherlands; Schmoyer & Cooper (2008) in the USA.

The majority of studies conclude that whilst the level of knowledge about hydrogen technology is generally low, the level of support for hydrogen technology is high. For example, Zachariah-Wolff & Hemmes (2006), based on a sample of the Belgian population, found a low level of public knowledge about hydrogen. Yet they also found that hydrogen, as a fuel for home heating and cars and buses, was perceived as environmentally friendly and the willingness to use hydrogen was rather high. Overall, the results of this study suggest that respondents have a positive attitude towards hydrogen investments and hydrogen applications. Similarly, the surveys carried out within the US Department of Energy's Hydrogen Program in 2004 and 2008 (Schmoyer, Truett, Cooper, & Chew, 2010), showed that only around 35% of the sample was able to provide a correct answer to eight questions about hydrogen technologies. The study by the DOE (Schmoyer, Truett, Cooper, & Chew, 2010), also found a low level of reported familiarity with hydrogen technologies. Specifically, almost 9 out of 10 individuals considered themselves "not at all familiar" or "slightly familiar" with hydrogen and fuel cell technologies. More recently, the study by Achterberg (2012), based on a representative sample of the Dutch population, found a high level of public support for investments in hydrogen technologies and for the use of hydrogen technologies in public transportation. Support for hydrogen differed in relation to individuals' knowledge of hydrogen technologies and their cultural predispositions (environmental concern and trust in science and technology) (ibid).

HFCEVs

A significant part of the studies on public acceptance of hydrogen and fuel cell technologies have focused on public reactions to fuel cell vehicles (mainly buses and passenger cars) (for a review see Altmann, Schmidt, Mourato, & O'Garra (2003) and Yetano Roche, Mourato, Fischedick, Pietzner, & Viebahn (2010)). Schulte, Hart, & Van der Vorst (2004), for instance, found that the response towards hydrogen vehicles was generally positive and levels of acceptance were high. Altmann et al. (2004), in a study of public perception of hydrogen buses in different locations, found that the support for hydrogen and fuel cells was generally high, that there was practically no opposition to the introduction of hydrogen fuel and hydrogen vehicles, that many people were undecided and needed more information, and that hydrogen was connected to positive (environment), negative (bomb, explosive) as well as neutral associations (physical properties). Heinz and Erdmann (2008), based on a survey in eight European cities, found that a majority of citizens (68%) would support a substitution of conventional buses by hydrogen buses and only 1% would object to this, but also that a significant 31% of the sample reported being indifferent or needing more information to come to a decision. Zachariah-Wolff and Hemmes, (2006) found that 92% of respondents would prefer to drive a hydrogen-powered fuel cell vehicle rather than a conventional car (all else being equal). The study by O'Garra, Mourato and Pearson (2008) on the attitudes towards the introduction of H_2 vehicles in London found that one third (32%) of respondents supported the introduction of H_2 vehicles, and less than 1% opposed them. Reasons for opposition were all related to risk. The majority (62%) of respondents, however, said that they would 'need more information'.

More recently, Zimmer and Welke (2012) found that 79% of respondents gave a clear vote for the introduction of hydrogen powered cars. Only 4% of respondents opposed the introduction of hydrogen powered-cars. Similar results were shown in the study by Tarigan, Bayer, Langhelle and Thesen (2012), where most part of the residents in one Norwegian region supported the introduction of hydrogen vehicles. Heo and Yoo (2013) measured the public's willingness to pay (WTP) for a large-scale introduction of H_2FC buses in Korea and found that the majority of respondents wanted to introduce H_2FC buses on a large scale regardless of their income, age, and education level. Achterberg (2014) found strong support (77%) for the application of hydrogen technology in public transportation such as buses, as well as a generalized perception that the use of hydrogen as a fuel is good for the environment. The study also found that support of hydrogen had declined between 2008 and 2013.

Hydrogen refuelling stations

Studies in various countries have also investigated public reactions to hydrogen fuelling stations. O'Garra, Mourato and Pearson (2008) investigated local attitudes towards the proposed installation of hydrogen storage facilities at existing fuelling stations throughout London. Confronted with the hypothetical construction of a hydrogen fuelling facility in their local petrol station, the majority of respondents (60%) indicated that they 'needed more information'. Support levels were low to moderate, with 25% of respondents supporting such a development. Only around 10% of respondents said they would oppose a proposed H_2 storage development taking place at their local fuelling station. They also found that residents living very close to a proposed H_2 facility were less likely to be opposed than residents living 200 to 500m away. Opposition was influenced by a lack of trust in safety regulations, non-environmental attitudes, and concerns about the existing local fuelling station.

Schmoyer, Truett, Cooper and Chew, (2010) asked respondents about their feelings about the possibility of their local gas station also selling hydrogen. A significant part (40%) of the sample that had a low level of knowledge regarding hydrogen reported not having a clear view on this. Around 50% of respondents reported feeling pleased or at ease about this scenario and only 10% reported feeling uneasy.

A study by Thesen and Langhelle (2008) and by Tarigan, Bayer, Langhelle and Thesen (2012) investigated the acceptability of hydrogen vehicles and filling stations among residents in the Greater Stavanger area (Norway) and compared the results with the findings from a London case study. The study also compared acceptance levels among Norwegian residents living very close to the fuelling stations and those living beyond the stations' site (one sample was drawn from residents living within a 1-km circle of the location of the filling station, and one control sample was drawn from the Greater Stavanger area). The study first showed that although only just over one third were clearly in favour of the introduction of hydrogen vehicles in London, the number in Greater Stavanger was close to 60%. The key determinants of acceptability were prior knowledge and awareness of hydrogen, sociodemographic background variables and environmental knowledge. The study also showed that support for the introduction of hydrogen vehicles was greater among people living closer to the filling station than in the region as such.

Huijts, De Groot, Molin and van Wee (2013) investigated the psychological determinants of citizens' support for a local hydrogen refuelling facility in The Netherlands. A causal model based on the technology acceptance framework was implemented. The study found that among respondents that received information about hydrogen as a fuel, hydrogen technology, and the opinion of stakeholders, around 62% supported the installation of the infrastructure, 27% expressed a neutral attitude and 11% opposed the installation. Respondents receiving no information about hydrogen were generally more neutral (the % of neutral voters was 45%) towards the installation of a hydrogen fuelling installation. The three strongest determinants of intention to act in favor of the technology were personal norm, positive affect and the perceived effects of the technology. For intention to act against the technology, these were personal norm, negative affect, and trust in the industry. In a more recent study, Huijts and van Wee (2015) found that psychological variables explained public acceptability better than the socio-demographic and spatial variables. The strongest predictors were positive affect, negative affect, expected local effects and expected societal and environmental effects.

Home fuel cells

Very few studies have investigated public or consumer acceptance of home fuel cells. In the study by Zachariah-Wolff and Hemmes (2006), respondents (a sample of the general population) were asked to what degree they were willing to use hydrogen applications in the domestic context, including the use of hydrogen as a mixture with natural gas and domestic fuel cells as micro-CHP "all else being equal." Respondents were presented with different scenarios for the use of micro-CHP in their homes. As the authors conclude, "the general willingness to use hydrogen-fuelled micro-CHP in homes was quite high: 94% if all things remain equal with conventional boilers". Increased risk of failure was the most important factor in the evaluation. The study also found that an increase of 10% on the capital cost of installation reduced significantly willingness to use (to 61%). Bellaby and Clark (2014), in a study among students visiting a "Hydrogen Research and Demonstration Centre" in the UK, also found evidence of public support for the use of hydrogen fuel cells in combined heat and power units. Students thought that, as the technology developed, people would switch to hydrogen from fossil fuel.

Overall, a large body of research on public attitudes towards hydrogen and fuel cell technologies has developed in the last two decades. Social research has mainly focused on describing levels of understanding and acceptance of hydrogen technologies, with a special emphasis on hydrogen fuel cell electric vehicles, as well as examining its determinants among national and specific populations. There are several limitations in the research literature that should be acknowledged. Firstly, there are very few comparative studies on acceptance of hydrogen and fuel cell technologies. The majority of the published studies concentrate their research on individual countries or populations. Secondly, very few studies rely on established analytical models for the key determinants of acceptability. Although this is not per se a limitation, it makes it more difficult to acknowledge the role of the various factors influencing public attitudes towards hydrogen and fuel cell technologies. Thirdly, several different measures have been used to assess acceptance and support, making it difficult to draw comparisons across studies for similar applications. Finally, it is not clear if participants in the studies have been informed of the main features of the studied applications and their potential consequences, raising the issue of "pseudo opinions" and "non-attitudes" (De Best-Waldhober and Daamen, 2006), produced when respondents express an opinion despite the fact that they know little about the object and do not have a stable attitude about it.

Methods

Design

The current study is based on survey data collected in seven European countries: Belgium, France, Germany, Norway, Slovenia, Spain and United Kingdom. A specific questionnaire to measure public attitudes towards hydrogen fuel cell technologies was developed by the research team. Participants, members of the general population aged 16 and over, were recruited from online panels in the seven countries.

Participants

Nationally-representative samples of approximately 1000 adults from each country took part in the online survey conducted by the market research firm Norstat. The sample consisted of Norstat panel members who had agreed to participate in an online market and social research. Using a quota sampling approach, the final sample of around 1000 participants per country was split equally across the two technologies (stationary residential hydrogen fuel cells and hydrogen fuel cell vehicles). The quotas were based on gender, education and age to ensure an overall approximation of the population of the country. Invitations to take part in the survey were sent to participants through the access panel system. All respondents received incentives in the form of gift cards for taking part in the survey. Data was collected during April and May 2016. Table 1 shows the socio-demographic characteristics of the sample in each country.

Table 1.
Demographic characteristics of study populations

Sample		BE	FR	DE	NO	SL	ES	UK
N		1021	1022	1011	1033	1014	1034	1013
Sex (male)		47%	48%	49%	49%	49%	49%	52%
Age group	18-34	27%	28%	23%	28%	27%	29%	28%
	35-44	18	18	18	19	19	21	18
	45-54	19	17	19	18	18	18	17
	55+	36	36	40	35	35	32	37
Education	Primary	13%	24%	,3%	8%	5%	8%	9%
	Secondary	46	25	75	40	60	31	30
	Tertiary (or higher education)	41	51	25	52	35	61	61
Size of place of residence	<2.000	9%	21%	8%	12%	27%	6%	12%
	2.000-20.000	46	33	31	29	38	19	23
	20.001-199.999	32	27	29	35	18	31	32
	200.000-1.000.000	7	10	19	17	14	23	17
	>1.000.000	5	9	13	6	2	21	16

Questionnaire

A questionnaire was developed by the research team to assess the levels of public awareness, understanding and acceptance of hydrogen and fuel cell technologies and applications. The design of the questionnaire also aimed at building a predictive model for the acceptance of FCH technologies based on segmented responses to FCH technologies, including factors known to be relevant in this context. The perspective is social-psychological, drawing partly on a technology acceptance model (Huijts, Molin, and Steg 2012; Huijts, Molin, and van Wee 2014) a model describing the causal links among the attitudinal elements that directly and indirectly affect technology acceptance.

The final questionnaire included items specifically developed by the research team to measure various dimensions of the public acceptance of energy technologies (Huijts, Molin, and van Wee 2014), as well as a selection of items from previous studies on public acceptance of hydrogen and fuel cell technologies, and other energy technologies in different countries (Achterberg, Houtman, van Bohemen and Manevska, 2010; De Best-Waldhober and Daamen, 2006; Huijts, De Groot, Molin, and van Wee, 2013; Huijts, Molin, and Steg, 2012; Truett, Schmoyer and Cooper, 2008).

The questionnaire was structured in five sections. The first section consisted of baseline questions (evaluation of problems, awareness on hydrogen fuel cells and initial evaluation). After the baseline questions, participants in the study were randomly split into Group A and Group B. Participants in Group A (around 500 participants) evaluated stationary fuel cells for home use in sections two, three and four. Participants in Group B (around 500 participants) evaluated HFC vehicles in the same section. The second section consisted of items aimed at measuring awareness, familiarity, affects and beliefs. Section three consisted of an evaluation of six specific consequences of the application (this exercise was inspired by the Information Choice Questionnaire, see De Best-Waldhober and Daamen, 2006 for more details). Section four consisted of items measuring global attitude, acceptance, preference and support (for residential fuel cell micro-CHP and for hydrogen fuel cell electric vehicles (FCEV)). The final section consisted of other items measuring trust, attitudinal predispositions, lifestyles and sociodemographics.

It was necessary to minimize the so-called problem of “pseudo opinions” and “non-attitudes” (De Best-Waldhober and Daamen, 2006), produced when respondents express an opinion despite the fact that they know little about the object and do not have a stable attitude about it, as this results in views that are unbalanced and very responsive to contextual change (De Best-Waldhober and Daamen, 2006; Fleishman et al. 2010). Accordingly, general and specific information about hydrogen fuel cells, residential fuel cells and hydrogen fuel cell electric vehicles (FCEV) was provided to participants after initial questions designed to test non-informed responses. In addition, specific information on six consequences or characteristics of the application was provided for residential fuel cell micro-CHP and for hydrogen fuel cell electric vehicles (FCEV). This information was based on available reports and interviews with experts. The three pages of information given to the respondents can be found in the Appendix. All information and questions were translated to the respective national languages.

Table 2

Dimensions included in the study and illustrative studies

Dimension	Definition	Studies
Awareness	Degree to which individuals are conscious, know, have heard of specific technologies or developments	Zimmer and Welke (2012)
Familiarity	Subjective knowledge and familiarity with the technology	DOE survey
Experience	Direct personal contact with hydrogen applications	Zimmer and Welke (2012)
Affect	Degree to which the technology generates various emotions in participants	Midden and Huijts, 2009
Evaluation of consequences	Degree to which individuals consider potential consequences an advantage or a disadvantage	De Best-Waldhober et al., 2008
Global attitude	Personal evaluation of the technology	De Best-Waldhober et al., 2008
Acceptance and Support	Degree to which the individual accepts and supports (attitudinal and behavioural acceptance) further developments in the technology.	Achterberg, 2014 Huijts (2012)
Trust	Trust in industry and governments to make good decisions and to succeed in implementing the technologies	Midden and Huijts, 2009
Other variables	Involvement and identity in energy and environmental issues Lifestyles	Axsen et al. (2012); Whitmarsh & O’Neill, (2010)

Table 3
Summary of variables, items and scales

Initial or uninformed evaluation of HFC
Overall, how do you feel about hydrogen fuel cell technologies as a possible solution for energy and environmental challenges? (Five response categories, from "Very bad" to "Very good")
Global informed evaluation of home HFC
Taking into account all the information, what is your overall evaluation of hydrogen fuel cell stationary home applications as a heating and electricity source? (Five response categories, from "Very bad" to "Very good")
Acceptance of home HFC
All else equal (price, comfort, maintenance cost, etc.), I would be happy to have a hydrogen fuel cell unit in my home in future (Five response categories, from "Strongly disagree" to "Strongly agree")
Support to home HFC
Public funding should be used to subsidize the purchase price of the fuel cell system (Five response categories, from "Strongly disagree" to "Strongly agree")
Self-reported likelihood of installing a home fuel cell (% likely and very likely)
Imagine that you are considering replacing your current heating system. How likely, if at all, would you be to install a hydrogen fuel cell system as a heating and electricity source? (Five response categories, from "Very unlikely" to "Very likely")
Global informed evaluation of home HFC (% of good and very good)
Taking into account the information above, what is your overall evaluation of hydrogen fuel cell cars? (Five response categories, from "Very bad" to "Very good")
Acceptance of HFCEVs
All else equal (cost, range, etc.), I would like to purchase a hydrogen fuel cell car in the future (Five response categories, from "Strongly disagree" to "Strongly agree")
Support for HFCEVs
Local municipalities should promote the substitution of conventional buses for hydrogen fuel-cell buses (Five response categories, from "Strongly disagree" to "Strongly agree")
Affects regarding home fuel cells and HFCEVs
To what extent does this technology evoke the following feelings in you, if at all? Negative affect: worry, aversion. Positive affect: hope, interest. (Five response categories, from "Not at all" to "Very much")
Perceived benefits/costs
What are your expectations with respect to this technology?
For home fuel cells: Cost too much to install – have acceptable costs; Cost too much to run – be affordable to run; Be very inconvenient (in terms of noise, vibration, specific location) – very convenient; Have a very negative – very positive effect on the environment; Require a high frequency of maintenance – low frequency of maintenance; Be very dangerous – very safe; Be inconvenient to use – user friendly (Five response categories)
For HFCEVs: be environmentally friendly – be environmentally harmful; have sufficient range – don't have a sufficient range; be easy – not easy to refuel / recharge; be safe to drive – not safe to drive; be reliable – unreliable; be economically affordable – economically not affordable; make my life easier – wouldn't make my life easier (Five response categories)
Preference for alternative technologies
How would you rate the following technologies to heat the home compared to hydrogen fuel cell systems? a) gas boilers; b) solar thermal. How would you rate the following types of cars compared to hydrogen fuel cell cars? A) electric cars; b) conventional cars. (Three response categories: a more negative option, about the same, a more positive option)
General trust
How much do you trust a) the industry in your country; b) the government in your country: (1) to make good decisions about hydrogen technologies? (2) to solve possible problems and succeed in implementing hydrogen technologies safely and in a responsible way? (Five response categories, from not at all to very much)

Analysis

For data analysis, we first used cross-tabs and comparison of means for bivariate analysis, with country of residence as an independent variable. Pearson's chi-square and F tests and Cramer's V and eta coefficient were used to evaluate the differences across cities. The association between acceptance of residential fuel cell micro-CHP and for hydrogen fuel cell electric vehicles (FCEV) (dependent variables) and a number of independent variables was examined using multiple regression models. Covariates were considered for inclusion in the model based on a priori hypothesis.

Results

Awareness and initial evaluation of HFC technologies

Across all seven countries, the level of public awareness of hydrogen and fuel cell technologies in the context of energy generation was below 50% (see Table 4). The highest levels of awareness were found in Germany and Norway, where almost 50% of respondents reported having heard of HFC technologies in the context of energy production. Around 40% of respondents were aware of HFC technologies in Belgium, Slovenia, France and United Kingdom. Only 30% of respondents reported having heard of these technologies in Spain. Public awareness of HFC residential stationary applications was lower than awareness of about hydrogen and fuel cell technologies in general, in all the countries studied. Around 25% of respondents reported having heard about residential fuel cells. The level of awareness ranged from 32% in Germany to 20% in Norway. Public awareness of HFCEV was higher than that for residential fuel cell units. Around 60% of participants in the whole sample reported having heard about HFCEVs. This percentage ranged from 85% in Norway to 47% in Spain.

Uninformed evaluation of HFC was generally positive among respondents in the seven countries. Almost 60% of respondents evaluated HFCs as a good or very good solution to energy challenges, 42% rated HFCs as a neutral solution, and less than 1% believed that HFCs were a bad or very bad solution to energy challenges. There were small (eta=0.10, p=0.001) but significant differences in the initial evaluation among the seven countries studied. The average initial evaluation of HFCs ranged from 3.81 in Slovenia, where 70% of respondents considered the technology as a good or very good solution and only 30% rated it as a neutral solution, to 3.56 in the United Kingdom, where 48% of respondents considered the technology a good or very good solution and 51% considered it a neutral solution.

Global evaluation and acceptance of home fuel cells

As shown in Table 5, after having read information about the specific consequences of residential fuel cells, around 6 out of 10 respondents (62%) in the whole sample rated the application as a good or very good technology (values 4 and 5 in the scale). The global evaluation of home fuel cells was more positive in Spain and Germany, where more than 65% of respondents considered the technology as a good or very good option, and slightly more negative in Norway, United Kingdom and France. In these three countries, the percentage of participants reporting a neutral evaluation of the application was significantly higher than in the rest of the countries (36%, 37% and 34% respectively).

The level of acceptance was high in the seven countries (around 60% of respondents reported being willing to have a hydrogen fuel cell unit installed in their home in the future (keeping all else equal)). There were moderate and significant differences among the countries. Acceptance of home fuel cells was higher in Germany, Slovenia and Spain, where around 70% of respondents would be happy to install a residential fuel cell micro-CHP in the future, and lower in France, Norway, Belgium and United Kingdom.

Table 4

Awareness of HFC applications and uninformed evaluation in the seven studied countries

	BE (%)	FR (%)	DE (%)	NO (%)	SL (%)	ES (%)	UK (%)	Total	Strength of the difference (Cramer's V)
Awareness of HFC	41	39	49	47	42	29	39	41	0.12*
Awareness of residential fuel cell micro-CHP	23	25	32	20	31	23	23	25	0.09*
Awareness of HFCEV	60	54	59	85	63	47	54	43	0.15*
Initial evaluation of HFC (% good or very good)	58	50	55	56	70	57	48	58	0.10* (eta)

**The difference is significant at the .05 level.*

Table 5

Acceptance of residential HFCs in the seven studied countries

	BE (%)	FR (%)	DE (%)	NO (%)	SL (%)	ES (%)	UK (%)	Total	Strength of the difference (eta)
Global evaluation of home HFC (% of good and very good)	64	61	66	51	69	68	57	62	0.14*
Acceptance (% agree and strongly agree)	60	55	71	58	71	71	61	64	0.15*
Support (% agree and strongly agree)	75	74	79	68	86	78	61	74	0.20*

**The difference is significant at the .05 level.*

Support for public funding to subsidize the price of residential fuel cell systems was generally high in the seven countries. On average, more than 70% of all respondents agreed to the use of public funds to subsidize the purchase price of a fuel cell installation. There were marked (eta= .20, p=0.001) and significant differences among the countries. For instance, whilst support to public funding of home HFC was very high in Slovenia (86%), it was markedly lower in United Kingdom (61%).

Global evaluation and acceptance of HFCEVs

Global informed evaluation of HFCEVs was generally positive in the seven countries (Table 6). On average, 63% of respondents rated HFCEVs as a good or very good option. Informed evaluation of HFCEVs was more positive in Slovenia and Norway and more neutral in France. But the differences among the countries were very small (eta= 0.07), although significant.

Acceptance of HFCEVs, measured as the willingness to purchase a hydrogen fuel cell car in the future (all else equal: cost, range, etc.), was also high in the seven countries. Relative to the informed evaluation, there were more marked differences in acceptance between the countries. The public acceptance of hydrogen fuel cell car in the future ranged from 72% in Norway and Spain to 55% in Belgium and United Kingdom (Table 6).

Support for the substitution of conventional buses for hydrogen fuel-cell buses in the local municipalities was very high in the seven countries (78%). Respondents in the United Kingdom and France reported a slightly lower level of support for the transition to HFC buses (71% and 74% respectively). The differences between the countries were significant but small.

Correlates of acceptance of home FC and HFCEVs

Four regression models were run to examine the association between independent variables (sociodemographic and attitudinal) and acceptance of home fuel cells and HFCEVs (Table 7). Models were not run for each of the countries because no significant interactions by country were observed for these independent variables.

In the first of the four models, and before controlling for attitudinal variables, gender and size of residence were weakly associated to acceptance of residential fuel cells. Male respondents reported a higher level of acceptance relative to female. Also those living in cities with more than one million inhabitants reported a higher level of acceptance relative to those living in smaller cities. There were no significant differences for educational level, age or income. After controlling for a number of attitudinal variables in the second model, positive affect was the strongest individual-level predictor of acceptance (Beta= .38, p= 0.00), followed by negative affect (Beta= -.15, p= 0.00), perceived benefits/costs (Beta= .10, p= 0.00), trust (Beta= .10, p=0.00), age (Beta= -.09, p= 0.00), preference for gas boilers (Beta= -.07, p= 0.00) and size of place of residence (Beta= .05, p= 0.00).

In the third model, and before controlling for attitudinal variables, gender and age were weakly associated with acceptance of HFCEV. Male respondents reported a higher level of acceptance relative to female. Also those in the younger age groups reported a higher level of acceptance. There were no significant differences for educational level, income or size of residence. In the fourth model, including all the variables in the model, positive affect was the strongest individual-level predictor of acceptance (Beta= .36, p= 0.00), followed by negative affect (Beta= -.15, p= 0.00), trust (Beta= .13, p=0.00), age (Beta= -.11, p= 0.00) preference for conventional cars (Beta= -.09, p= 0.00) and perceived benefits/costs (Beta= .04, p= 0.00).

Discussion

This study examines public attitudes towards residential fuel cell micro-CHP and hydrogen fuel cell electric vehicles (FCEV) in seven European countries. The data from a questionnaire survey with representative samples of the general population in Belgium, France, Germany, Norway, Slovenia, Spain and United Kingdom allowed us to examine cross-

Table 6
Acceptance of HFCEVs in the seven studied countries

	BE (%)	FR (%)	DE (%)	NO (%)	SL (%)	ES (%)	UK (%)	Total	Strength of the difference (eta)
Global evaluation of HFCEV (% of good and very good)	61	56	62	66	71	64	64	63	0.07*
Acceptance (% agree and strongly agree)	55	58	66	72	65	72	56	63	0.18*
Support (% agree and strongly agree)	79	74	82	80	82	81	71	78	0.11*

Table 7
Regression coefficients

	Acceptance of residential fuel cell micro-CHP		Acceptance of HFCEV	
	Model 1		Model 3	
	Beta	p-value	Beta	p-value
Gender (1=woman)	-,06	,00	-,08	,00
Age	-,02	,17	-,07	,00
Educational level	-,01	,55	,04	,04
Size of place of residence	,06	,00	,03	,05
Income	,02	,24	,03	,06
R2	0.01	.00	0.02	.00
	Model 2		Model 4	
Gender	-,01	,41	-,01	,63
Age	-,09	,00	-,11	,00
Educational level	-,03	,02	,002	,88
Size of place of residence	,05	,00	,03	,06
Income	-,02	,13	-,01	,69
Familiarity	,005	,74	,05	,00
Perceived benefits/costs	,10	,00	,04	,00
Positive affect	,38	,00	,36	,00
Negative affect	-,15	,00	-,15	,00
Preference for gas boilers	-,07	,00	--	--
Preference for solar thermal	-,02	,24	--	--
Preference for electric cars	--	--	-,03	,08
Preference for conventional cars	--	--	-,09	,00
General trust	,10	,00	,13	,00
R2	0.25	.00	0.26	.00

country differences in public awareness, beliefs about the benefits and the costs, acceptance and support of fuel cell applications. The study also allowed us to examine demographic and attitudinal correlates of acceptance of fuel cell applications. This research represents an important step in understanding cross-country variations in public attitudes towards hydrogen and fuel cell technologies.

Principal findings and interpretation

The data show that less than half of the population in the seven countries are aware of the existence of hydrogen and fuel cell technologies in the context of energy production. Public awareness seems to be significantly lower for fuel cell residential applications and higher for hydrogen fuel cell vehicles. The level of familiarity with both applications is low, and less than 10% of respondents consider themselves familiar with these applications. In general, respondents in the seven countries have a positive initial attitude towards HFC technologies. After processing relevant information, respondents in the seven countries are likely to accept and support the adoption of residential fuel cells and HFCEVs. On average, levels of acceptance and support are significantly high (more than six out of ten respondents could be considered as supporters of the technology) and very similar for home fuel cells and fuel cell cars, with the exception of Norway, where acceptance is significantly higher for fuel cell vehicles relative to home fuel cells. Self-reported likelihood of purchasing a fuel cell system or vehicle is very low in the seven studied populations. Overall, the seven studied populations are similar in their attitudes towards HFC technologies. However, the results point to small to moderate significant differences in awareness and acceptance of HFC applications across countries. For instance, we observed higher levels of awareness of HFC applications in Germany and Norway, and a lower level in Spain, France and the UK. Acceptance of home fuel cells was clearly higher in Germany, Slovenia and Spain, whilst acceptance of HFCEVs was higher in Norway and Spain. We finally found that affect, perceived benefits, trust and age were significant correlates of acceptance of home fuel cells. For acceptance of HFCEVs, affect, trust, age and preference for conventional cars were the most associated variables.

The finding that less than half of the population in the seven studied population is aware of hydrogen and fuel cell technologies in the context of energy production, and also that awareness is higher for fuel cell vehicles than for residential fuel cells was somehow expected. The results are very similar to previous reports by the Eurobarometer (Eurobarometer, 2007), where five out of ten EU citizens reported having heard about hydrogen energy and cars and four out of ten reported having heard about fuel cells (Eurobarometer, 2007). Hydrogen and fuel cell vehicles are, in a sense, more popular than residential fuel cell applications, which is perhaps due to a distinct level of media coverage. But overall, familiarity with these applications is low, a finding that has been previously documented by the DOE study, where almost 9 out of 10 individuals considered themselves “not at all familiar” or “slightly familiar” with hydrogen and fuel cell technologies.

All in all, the results of the study appear to suggest, first, that hydrogen and fuel cells tend to invoke positive thoughts among respondents. This is relevant given that research on public perception of energy technologies has shown that individuals infer some of the attributes of the technology from a label, product names, technology names or brand names that function as heuristic cues (Van Rijnsoever, Van Mossel and Broecks, 2015). This is also consistent with previous studies finding that hydrogen is generally connected to positive associations (e.g. environmentally friendly technology) (Schulte, Hart, and Van der Vorst 2004; Zachariah-Wolff and Hemmes 2006).

Second, the study shows that after processing relevant information, most people in the seven countries consider themselves likely to accept and support the adoption of residential fuel cells and hydrogen fuel cell electric vehicles *all other things being equal*. This is consistent with results from previous studies showing a positive attitude towards hydrogen applications as well as a high level of acceptance and support for the application of hydrogen technologies in the transportation and the residential sectors (Schulte et al. 2004; Zachariah-Wolff and Hemmes 2006; Zimmer and Welke 2012).

Of course we know that, at the moment, all other things are not equal and this poses a significant challenge for hydrogen fuel cell vehicles. We found that respondents generally consider themselves unlikely to buy a residential fuel cell micro-CHP or a hydrogen fuel cell electric vehicle in the near future. Perceived costs and limitations of HFCs technologies, such as the price of purchasing the application, technological immaturity or lack of refuelling stations, seem to limit respondents’ willingness to adopt HFC applications in the future. As shown by Zachariah-Wolff and Hemmes (2006), an increase of 10% on the capital cost of installation reduced significantly, more than 30 percentage points, willing to use a fuel cell residential unit. We found that another explanatory factor limiting the public’s willingness to adopt HFC technologies might be a slight preference for alternative technologies (e.g. solar thermal and ground source heat pump and hybrid and full electric cars). According to the data in the study, this may be especially relevant in some countries.

The comparison between the seven countries seems to indicate that, overall, the seven studied populations are similar in their attitudes towards HFC technologies. However, there are significant differences across countries that require some interpretation. Are these differences the result of different levels of market penetration, government and industry support to HFC technologies? Do the responses reflect differences in national cultural predispositions regarding the acceptance of new energy technologies or energy issues? So far, studies on various countries such as Germany, the Netherlands, the UK and Netherlands tend to show high levels of public acceptance of hydrogen technologies, with percentages of acceptance that vary between 60 to 80% (Schulte et al., 2004; Thesen and Langhelle, 2008; Zimmer and Welke, 2012; Huijts et al., 2013), percentages that are very similar to our results. But there have been very few attempts to examine and interpret the differences between countries in terms of public support.

One likely interpretation is that in those countries where there is a strong policy support for the technology, backed by government and industry, public awareness tends to be higher. For instance, levels of public awareness of hydrogen and fuel cell technologies are higher in Germany and Norway, where policy support is, in principle, strongest. However, the data also shows that policy support is far from perfectly associated to the levels of acceptance found among the public. For instance, the global evaluation and acceptance of HFC technologies is significantly higher among respondents in Slovenia and Spain, and lower among respondents in United Kingdom and France, with differences reaching twenty percentage points. We have not sought to regress against R&D indicators, though – as with many of the findings, this merits further investigation. We can more confidently say that support and opposition is associated with specific characteristics that span countries (gender, education, urban and affluence, prior attitudes towards energy issues and towards specific alternative energy technologies (Pietzner et al. 2011)), though again further work would be needed to characterise any further associations.

Finally, the explanatory power of the regression model was moderate. Acceptance of HFC applications is partially determined by positive (mainly interest) and negative affect (mainly worry), the perception of benefits and costs of the applications, trust, age and preference for alternative technologies. Interestingly, the weight of these factors in acceptance slightly varies between home fuel cells and fuel cell vehicles. Other relevant factors with a smaller potential effect on acceptance are familiarity, size of place of residence and educational level. Although not perfectly comparable, the results are in line with previous findings. Huijts and van Wee (2015), for instance, found that psychological variables explained public acceptability of hydrogen refuelling stations better than the socio-demographic and spatial variables. The strongest predictors in this study were positive affect, negative affect, expected local effects and expected societal and environmental effects. None of the models tested in our study fully explain acceptance of HFC applications, but they do help in understanding the correlates of acceptance. There may be other factors not included in the study that might further explain acceptance of HFC applications (e.g. norms and values that we could not include in what is already quite a lengthy questionnaire) (Huijts et al. 2012). Additionally, attitudes and opinions might be unstable and also easily affected by contextual factors.

Overall, the results contribute to improve our understanding of public acceptance of hydrogen and fuel cell technologies through cross-national research. As markets for hydrogen and fuel cell technologies develop, public and consumer acceptance will likely play a role in the success of hydrogen fuel cells, both in the residential and the transportation sectors. Acceptance of hydrogen and fuel cell technologies will likely vary across time, countries and regions and segments of the population. Future research will provide the evidence needed to examine the trends of public acceptance of HFCs and attempt to document and explain some of the observations in this report.

Limitations

Some limitations of our study should be discussed. First, as the respondents were not familiar with the technology and the specific applications under study, there is the risk of collecting unstable attitudes or pseudo-opinions. To limit this problem, we provided participants in the study neutral general information about the technology, in addition to specific information about the consequences of residential fuel cells and hydrogen fuel cell electric vehicles. The information was carefully crafted by the research team in collaboration with experts in the field of hydrogen and fuel cells. We asked participants to evaluate these consequences, but in general we cannot be sure of the extent to which participants had the capacity and motivation to carefully process all the information provided (the equivalent of two-pages). Second, there is also the question of measurement invariance and internal validity. To ensure the validity of the measures, many of the items in the questionnaire were derived from previous studies on public acceptance of hydrogen and fuel cell technologies. Special attention was also paid to the translation of the questionnaires into the various languages to ensure that the questionnaire was measuring the same concept in the same way across various populations of respondents. Other technical measures were adopted during the data collection (online) process by the recruiting company. Finally, the survey investigates attitudes to prospective, hypothetical situations and for the most part cannot reflect respondents' actual experiences. As with all such studies, while every attempt is made to maximise reliability, only the future will tell how people actually respond to hydrogen fuel cell applications in actual, future contexts.

Conclusion

The present study compared countries with different levels of hydrogen and fuel cell deployment in terms of the public's attitudes. It seems that the majority of the population in the seven studied countries have a positive attitude towards HFC technologies. Levels of acceptance and support are generally high in the seven countries. Overall, the seven studied populations are similar in their attitudes towards HFC technologies. However, the results point to relevant differences in awareness and acceptance of HFC applications across countries.

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Annex

Introductory information

Home hydrogen fuel cells

For many years, electricity has mostly been generated in large-scale power stations. However with the increasing use of renewable energy, power is being generated with smaller and more numerous devices. Stationary fuel cells are another example of this trend. When located in the home, they allow households to generate part of the electricity and heat they require. As fuel cells are very efficient and can generate electricity from gas, they can reduce the amount of gas that a household needs to buy and eliminate the need to buy electricity.

About the size of a washing machine and powered by fuel cell technology, these fuel cell applications can be installed in a home utility room. The fuel cell system is connected to the normal gas supply and hot water unit, and then to the home's heating and electricity system. Hydrogen is generated from the home's natural gas supply and is fed to the fuel cell.

Stationary fuel cells can be also installed in buildings such as apartment blocks, to provide central heat and electricity to households. So far, large capacity fuel cells are utilized in some countries for schools, hospitals, and other energy-intensive facilities. But multi-family residential buildings represent a new opportunity for fuel cell technology because of their ability to continually provide electricity and heat.

Fuel-cell hydrogen vehicles

Fuel cell hydrogen vehicles use hydrogen gas to power an electric motor. Unlike conventional vehicles which run on gasoline or diesel, fuel cell vehicles combine hydrogen and oxygen on a fuel cell to produce electricity, which runs an electric motor.

Unlike battery-powered electric vehicles, fuel cell vehicles create electricity in an on-board fuel cell, usually using stored hydrogen (from a refuelling hydrogen station) and oxygen from the air.

Fuel-cell hydrogen cars have to be refilled with hydrogen from a filling station. Refuelling a fuel cell vehicle is comparable to refuelling a conventional car. It takes less than 10 minutes to fill current models. Once filled, the driving ranges of a fuel cell vehicle vary, but are expected to be around 300-450 km.

Although a few automakers currently offer FCEVs, today, every major car manufacturer has some sort of fuel-cell development program or partnership in the works.

Information provided for the evaluation of consequences exercise

Stationary applications for residential use

They would reduce the need to purchase electricity from a power company

Combining the production of on-site local heat with local electricity generation to meet on-site energy needs for both can save around 25% of the primary energy needed.

They would reduce CO2 emissions

A typical fuel cell micro combined heat and power system, using natural gas as the hydrogen source and comprising a fuel cell unit and hot water tank, can reduce CO2 emissions by up to 50% compared to the separate generation of heat and power.

High initial capital costs

As of December 2012, Panasonic and Tokyo Gas Co., Ltd. sold Ene-Farm units (full cell units that convert natural gas to heat and electricity) in Japan for a price of around 20.000 € before installation.

House space requirements

Installing a domestic fuel cell micro-CHP system requires around 0.65 m2 (about the size of fridge freezer).

It will reduce the cost of producing energy

Operating costs for home fuel cells can be as low as 10 cents per kWh for electricity. Residential systems are advertised by their manufacturers as reducing household bills by 450-1000 euros per year.

Similar risks to other fuels

Like any other fuel, hydrogen poses risks if not properly handled. Some of the properties of hydrogen make it potentially less hazardous than natural gas, petrol and diesel, while other characteristics make it more dangerous in particular situations. Specific precautions, such as good venting, need to be in place for hydrogen just as for many other fuels.

Hydrogen fuel cell electric vehicles

They would reduce the need for petroleum

Fuel cell vehicles use hydrogen gas and oxygen to power an electric motor. As hydrogen can be produced from a variety of domestic resources, hydrogen vehicles would reduce the need for petroleum.

Lower CO2 emissions than conventional cars

When oxygen and hydrogen react, they produce only water and heat, making hydrogen vehicles "zero-emissions" vehicles (like battery-powered electric vehicles). Total CO2 emissions depend on the source of energy used to produce the hydrogen. If solar, wind or other renewable resources generate the electricity, hydrogen could be produced without any carbon emissions at all. If the electricity used to produce hydrogen comes from natural gas, cars and buses cut emissions by over 30 percent when compared with their gasoline-powered counterparts.

Price of fuel cell material

The cost of the vehicles powered by hydrogen is still a key issue. Platinum is one of the most commonly used catalysts for fuel cells, but it is a very expensive and scarce resource. Initial pricing of Toyota Mirai, for instance, has been set at 53 231 € (state incentives in some countries could reduce the price).

Price of hydrogen

Hydrogen fuel cars are, on a simple per km basis, cheaper to run than regular gasoline engines. Right now, state-of-the-art hydrogen extraction from natural gas, pressurized and delivered to the customer, costs, before taxes, less than 1 euro for a liter of gasoline equivalent.

Infrastructure needed

New infrastructure will be needed for hydrogen refueling. Very few countries have more than 15 operational hydrogen filling stations and the network is only slowly growing. Interested drivers should ensure they live near hydrogen refueling stations.

Range

Current hydrogen cars have a range of around 450 km. This is a higher range than the majority of Electric Vehicles in the market and a lower range as compared to the performance of diesel vehicles.

Safety issues

Hydrogen poses risks of the same order of magnitude as other fuels. In a collision in an open space, a hydrogen fuel cell car should have less potential hazard than either natural gas or a gasoline vehicle. A potential risk is a release in an enclosed home garage, where an accumulation of hydrogen could lead to fire or explosion if no hydrogen detection or risk mitigation devices or measures are applied (such as passive or active ventilation)

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