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Consumer attitudes to fuel cell vehicles post trial in the United Kingdom

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ABSTRACT

Fuel cell cehicles (FCVs) have clear societal and environmental benefits and can help mitigate the issues of climate change, urban air pollution and oil dependence. In order for FCVs to have the biggest impact on these issues they need to be employed in large numbers. First, though, they need to be adopted by consumers. Their acceptance depends on positive consumer attitudes towards the vehicles. Currently there is a limited understanding within the literature on how consumers perceive FCVs and what the likelihood of adoption by consumers would be, despite significant governmental and organisational investments into the technology. Therefore this study assesses consumer attitudes towards FCVs in the United Kingdom. 81 persons drove a Hyundai FCV at the Low Carbon Vehicle Event in September 2015 of which 30 took part in this study. The results show that at present FCVs are perceived mostly as being similar to incumbent internal combustion engine vehicles. This is an admirable technical achievement, however in order for consumers to adopt FCVs they will need to be perceived as having distinctive benefits. Two significant barriers to the adoption of FCVs are observed in this sample: high costs and lack of refuelling infrastructure. This paper goes on to make suggestions on how and which beneficial attributes of the vehicles can be promoted to consumers and also makes suggestions on how the barriers can be overcame so that FCVs will be adopted by consumers.

Introduction

The widespread deployment of fuel cell vehicles (FCVs) is important because of the societal and environmental benefits that they possess [1–5]. Policy makers are keen to see FCVs taken up by commercial organisations and by consumers as they can help solve the long-standing issues of global climate change, urban air pollution and energy security [6–8]. Furthermore they have the potential to contribute toward grid power balancing, as any oversupply of power can be stored as hydrogen gas to be later used in a FCV [9]. This is likely to become a problem due to growing market shares of intermittent renewables, predominantly wind and solar in electricity grids. However, in order for FCVs to contribute to solving these issues, they will need to be adopted by consumers.

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FCVs are approaching market entry, with recent developments by some of the worlds largest automotive companies meaning there are now commercial offerings. These vehicles are an innovation, an innovation is any new technology, product or idea that is perceived as different from the current technology used by consumers [10]. FCVs contain many new technologies, including the fuel cell (FC) its balance of plant and the electric motors. The way in which the vehicles are refuelled is also different to that of an ICEV, requiring hydrogen fuel. These differences mean the people who will adopt them perceive the vehicles as being an innovation. Thanks to Rogers' Theory [10] it has long been understood that in order for consumers to adopt an innovation, it needs to have ‘relative advantage’. This means that an innovation needs to be perceived as better than the technology that it supersedes. If a technology is merely perceived as similar to the incumbent, consumers will not be motivated to adopt it. This is especially true when an innovation is more expensive than the preceding technology [10–13]. FCVs are more expensive than Internal Combustion Engine Vehicles (ICEVs) and Battery Electric Vehicles (BEVs), with the exception of Tesla BEVs, which cost US$70,000–105,000 [14]. This situation could change in the future with higher volume productions of FCVs, but the same can be said for BEVs. Nevertheless in the early market FCVs will exceed the price of an average ICEV and most BEVs. Therefore they must have relative advantage. This must be a clearly perceived from the point of view of the consumer, not societal and environmental benefits which are the concern of policy makers. Innovations that lack relative advantage suffer from slow rates of adoption, and when adoption does occur discontinuance is high [10].

This paper presents data from 30 participants in a FCV trial in the United Kingdom (UK). The aim of the study was to assess consumer attitudes toward FCVs with the objective of understanding what their perception of the relative advantage of the vehicles is. In doing so, a greater understanding of the likelihood of successful FCV market entry can be gained. This sample is unique as it is the first in the UK and Europe to assess the attitudes toward FCVs in this region. It is only the second study globally to do this, with the first being in the USA in 2009 [3]. It is the first study to assess attitudes of consumers who have driven both a FCV and a BEV. This is important because consumers are likely to have the choice between a BEV and FCV with future vehicle purchases. Previous studies have only considered FCVs in comparison with ICEVs, and do not pay attention to the implications a further choice between FCV and BEV can bring to consumers. This limitation was mentioned by Ref. [15] who called for FCV research to be conducted in the context of both ICEVs and BEVs. The FCV in this study is the Hyundai IX35 FCV, which was the first commercially available FCV on the market [16]. The characteristics of this vehicle can be seen in Table 1, in comparison to a Hyundai IX35 ICEV.

Table 1 – Features of the Hyundai IX35 FCV compared to its ICEV counterpart [17,18]. Note that in some markets the Hyundai IX35 is marketed as the Hyundai Tucson.

	Hyundai IX35 FCV	Hyundai IX35 ICEV
Price	£53,000	£18,695
Range	369 miles	611 miles
Refuel time	10 minutes	3–5 minutes
Acceleration (0–60mph)	12.5 seconds	11.5 seconds
Top speed	99 mph	113 mph
Efficiency (mpge)	51 (US EPA)	44.8 (NEDC)
Fuel running cost (estimate)	15p/mile	11p/mile

Existing fuel cell vehicle literature

Previous research into FCVs has suggested that barriers to adoption of the vehicles include high costs, lack of infrastructure, and perceived safety issues [15,19–23]. All of these suggestions are made without empirical evidence from people who have experience with a FCV. They either use case study data, or gather evidence from members of the general public and ask them questions about their opinions of FCVs. None of the consumers in these studies have ever driven a FCV. Therefore the data is only based on consumers' estimations of what the vehicles might be like. This data may not yield meaningful results as only 8% of the general public have been found to have good knowledge of FCVs [24]. Within the literature there is one exception: the study undertaken in California in 2009 by Martin et al. [3] allowed people to drive in a FCV before giving their opinion. This study found that consumers did not have safety concerns and the ride and drives were found to improve consumer perceptions of FCVs. The study is now 6 years old, therefore may be out of date due to technological advancements in FCVs and also due to changes in the nature of the automotive market which now contains close to three quarters of a million BEVs [25]. A further potential limitation of that study is that the results could potentially be biased due to participants not being random. Respondents were from agencies such as California Air Resources Board, California Fuel Cell Partnership and from universities. This sample may have more positive opinions of FCVs than the general population due to the background of participants.

Methodology

Respondents were recruited for this study at the Low Carbon Vehicles 2015 event in Millbrook, UK. The event is an annual showcase of low emission vehicles, including advanced ICEVs, HEVs, PHEV, BEVs and FCVs. In 2015 there were 2852 visitors to the event and 103 low carbon vehicles were on display. Visitors to the event have the opportunity to take the majority of the vehicles on display out on test drives. The test drive route is at the Millbrook Proving Ground in Bedfordshire, UK. The route involves a drive around the 5 km Alpine Handling Circuit and the 3.2 km High Speed Bowl. This allows drivers to experience braking, acceleration, road handling, and the top speed of vehicles. This event was selected as it would attract persons who have interest in BEVs and FCVs therefore may be potential early adopters. This means that the data will not be representative of the general population's opinions of FCVs; but it is still valid, though, as data that will be indicative of the opinions that early adopters have of FCVs. This is important because – by definition – early adopters will be the first people to purchase the vehicles. At the event, 81 attendees drove the FCVs and of these 30 took part in this study. What makes this sample unique is that most consumers in this study have experience of both a FCV and a BEV, with 86.7% of consumers having driven both types of vehicle. Therefore they are able to make direct comparisons between FCVs, BEVs, and ICEVs. After respondents had taken part in the trial drive of the FCVs they were asked a series of questions relating to how they perceive the vehicles. Questions first measured how they saw the vehicles in comparison with ICEVs. Then respondents were asked to compare FCVs with BEVs. Finally respondents were asked qualitative questions exploring what they liked and disliked about the FCV drive.

Results & discussion

Sample population

The socio-economic profile of respondents can be seen in Table 2. The table also includes data from the sample of 340 early adopters of BEVs so that comparisons can be made between each sample. For the FCV trial sample the average number of vehicles per household is 2.45. Age of respondents is spread widely with most between 25 and 54. There are a high proportion of males in this study (86.7%), which might simply be due to the type of event they were attending. 61.5% of respondents have a household income of more than £50,000. Level of education is high with 86.2% having received a university education and 62.1% having achieved a post-graduate degree. Respondents' professions are mostly technical such as automotive, aerospace or control engineering along with university academics and some from the public sector. In summary, respondents have a high number of household cars, are mostly male, have high incomes, are highly educated and have technical professions. The sample therefore may have the same socio-economic attributes as typical automotive early adopters as reported in the literature [26–32].

To ensure that the FCV trial study is representative of early adopters the t-test and chi-square are used to compare this sample with a sample of actual BEV early adopters from Ref. [33]. Directly comparable data for income was not available

Table 2 – Socio-economic profile of the respondents in this study (N = 30) and socio-economic profile of BEV early adopters from Ref. [33].

		FCV trial sample		Early adopters of BEVs sample	
		Count	Percentage %	Count	Percentage %
Number of cars in household	1	8	27.6	41	12.1
	2	9	31.0	163	47.9
	3	6	20.7	84	24.7
	4	3	10.3	37	10.9
	5	3	10.0	15	4.4
Number of people in household	1	4	13.3	38	11.2
	2	11	36.7	133	39.1
	3	5	16.7	53	15.6
	4	6	20.0	84	24.7
	5	4	13.3	32	9.4
Age	17–24	1	3.3	4	1.2
	25–34	12	40.0	39	11.5
	35–44	3	10.0	86	25.3
	45–54	9	30.0	88	25.9
	55–64	5	16.7	77	22.6
	65–74	0	0	36	10.6
	75–84	0	0	9	2.6
	85+	0	0	1	0.3
Gender	Female	4	13.3	25	7.4
	Male	26	86.7	315	92.6
Household income	£10,001–20,000	2	7.7		
	£20,001–30,000	1	3.8		
	£30,001–40,000	1	3.8		
	£40,001–50,000	6	23.1		
	£50,001–60,000	2	7.7		
	£60,001–70,000	6	23.1		
	£70,001–80,000	2	7.7		
	£80,001–90,000	2	7.7		
	£90,001–100,000	0	0.0		
	>£100,000	4	15.4		
Highest level of education	A level or equivalent	4	13.8	42	12.5
	Undergraduate degree or equivalent	7	24.1	136	40.6
	Masters or equivalent	12	41.4	94	28.1
	Doctorate or equivalent	6	20.7	55	16.4
	Other	0	0	8	2.4

Table 3 – T-test results comparing the means for household vehicles and household cars for the FCV trial participants sample and a sample of early adopters of BEVs.

Attribute	Group	Mean	Std. deviation	Std. error mean	T-test for equality of means	
					Sig. (2-tailed)	Mean difference
Number of people in household	FCV trial participants	2.833	1.2888	0.2353	0.956	−0.0127
	Early adopters of BEVs	2.821	1.1974	0.0649		
Number of cars in household	FCV trial participants	2.448	1.298	0.241	0.886	0.0282
	Early adopters of BEVs	2.476	0.9878	0.0536		

from the BEV survey and therefore is not included here. The t-test compared the means for number of cars in the household and number of people in the household (Table 3). No statistically significant differences were observed. Chi-square was used to compare age, gender and highest level of education (Table 4). This revelled no significant difference between gender and education. However age is significantly different between samples, with members of the FCV trial being younger on average. This suggests that the respondents in this study are representative of automotive early adopters, however are of younger age, meaning they may become adopters as they become older. It can therefore be safely assumed that the sample taken at the event is also typical of any other sample of automotive early adopters. This makes their opinions of the vehicles more instructive and meaningful, as these types of people will be the early buyers of automotive innovations, such as FCVs, in the future. Indeed, 30% of the sample has previously owned a low emission vehicle, including 5 BEVs, 4 PHEVs and 3 HEVs.

Opinions of fuel cell vehicles

The unbroken red line (in the web version) in Fig. 1 shows how participants perceive the FCV they have just driven. This shows that the brand, image/looks, range, time to refuel, running costs and life style fit of a FCV are perceived as similar to that of an ICEV. The purchase price of a FCV is perceived as being far worse than an ICEV. Interviewee perceptions of performance and fuel economy are slightly superior and environmental impacts are far superior compared to ICEVs. Therefore FCVs perform worse in 1 area, similar in 6 and superior in 3.

Fig. 1 also shows consumer perceptions of BEVs from Ref. [33]. The perceptions presented here are indicative of what steered the consumer decision to adopt this innovation. The broken green line shows data from low-end adopters (n = 185) who are mainly adopters of the Nissan Leaf (83.7%), and the broken blue line shows results for high-end adopters (n = 155) who are all adopters of Tesla BEVs. This shows that low-end BEVs are perceived as being superior to ICEVs in 5 areas, similar in 2 and worse in 3. High-end BEVs are superior in 7 areas, similar in 3 and worse in none. As Fig. 1 shows the perceptions consumers have of FCVs mostly fall short of the perceptions adopters have of BEVs. However, there are 2 areas where perceptions of FCVs are higher than those of low-end BEVs. These are range and time to refuel. There is 1 area where a FCV is perceived as superior compared to a high-end BEV, and again this is range. This is potentially detrimental as it suggests that BEVs may have more relative advantage compared to ICEVs than FCVs do, which could mean consumers would preferentially adopt BEVs in the future. In order to understand whether the differences in Fig. 1 are statistically significant, the t-test is used to compare differences between each BEV sample and the FCV trial sample. The t-test is used rather than the f-test, which would compare the averages between all three samples, as the significant differences between the high and low-end sample would influence the results.

The results can be seen in Table 5. The table shows the mean, standard deviation, standard error and then the results for the T-test equality of means significance and mean difference. For high-end adopters the significant difference (Sig. (2 tailed)) for brand, image/looks, purchase price, performance, fuel economy, lifestyle fit and running costs is <0.001, with high-end adopters perceptions of these being superior to the LCV trial sample. The means for the attributes range, time to refuel and environmental impacts are not significantly different suggesting that consumers perceive these attributes similarly for high-end BEVs and FCVs. For low-end adopters the significant difference for purchase price, range, fuel economy, life style fit & running costs is <0.001, with low-end adopters' perceptions of these being superior to the LCV trial sample. The means for the attributes performance and time to refuel are significantly different at <0.05, with performance being superior, but time to refuel being worse for low-end BEVs. The means for brand, image/looks and environmental impacts are not significantly different.

Fig. 2 shows responses to the same question as above, however this time respondents were asked to compare a FCV to a BEV. This shows that a FCV is perceived as having similar brand, image/looks, environmental impacts, fuel economy and performance but worse running costs and purchase price. Life style fit is perceived as slightly superior and range and time to refuel are perceived as far superior compared to BEVs. Therefore compared to a BEV the benefits of a FCV are due to longer ranges and shorter refuelling times. These data support the results found above; therefore the relative advantage of FCVs is due to their range and quick refuelling times, but also

Table 4 – Chi-square results comparing the results for gender, age and highest level of education for the FCV trial participants sample and a sample of early adopters of BEVs (* ≤0.001).**

Attribute	Chi-square	df	Significance (p)
Gender	1.365	1	0.243
Age	25.59	7	0.001***
Highest level of education	4.481	4	0.345

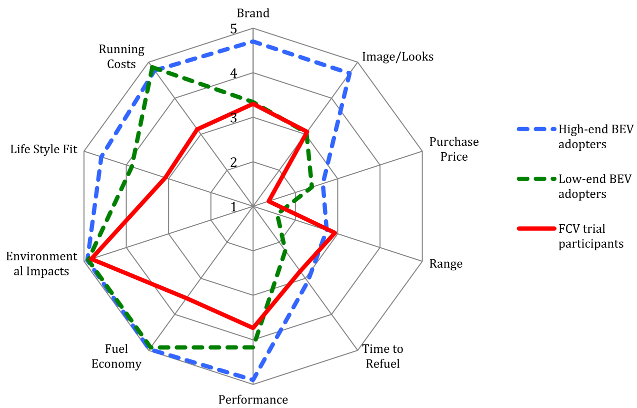

Fig. 1 – Answers to the question "Considering each of the following attributes how do you think a FCV (or BEV) compares to an ICEV?" with answers on a Likert scale of 5 = far superior, 4 = slightly superior, 3 = similar, 2 = slightly worse, 1 = far worse.

due to their performance, improved environmental impact, and fuel economy in comparison to an ICEV.

The data presented above is quantitative with a limited number of response options. Therefore FCV trial participants were asked a qualitative question; "What did you like about the fuel cell vehicle?". The purpose of this question was to understand any benefits of the vehicles that the previous question may have overlooked. The emergent topics from this question can be seen in Fig. 3. The most commonly mentioned benefit was the vehicle's quietness. Respondents also stated that they believe the range was a benefit, especially compared to a BEV. They perceived the vehicles as representing 'new technology'. They also liked the acceleration of the vehicles. They believed this created a positive driving experience. The low environmental impacts of the vehicles were also perceived as a positive aspect of FCVs.

Adopters were also asked about the shortcomings of the vehicles with the question "What didn't you like about the vehicle?" This revealed that the current lack of hydrogen refuelling infrastructure and high purchase prices are the most significant shortcomings of FCVs. The lack of refuelling infrastructure was mentioned by 19 out of 30 and high purchase prices by 18 out of 30 of the respondents (Fig. 4). This is not a new finding, as it has previously been stated by Refs. [3,5,34,35], but this does reiterate the importance of solving these barriers for adoption. Further shortcomings are high running costs, the source of hydrogen being perceived as mostly fossil fuels and thus not sustainable.

Table 5 – T-test results for the comparison between the means of the LCV trial study and the high-end BEV sample and the low-end BEV sample. Note that separate T-tests were used to compare the LCV trial data to the high-end data, and then the LCV data to the low-end data (* ≤0.05, ** ≤0.01, * ≤0.001).**

	Group	Mean	Std. deviation	Std. error mean	T-test for equality of means	
					Sig. (2-tailed)	Mean difference
Brand	FCV trial participants	3.3	0.6513	0.1189		
	High-end BEV adopters	4.703	0.6155	0.0494	<0.001***	1.403
	Low-end BEV adopters	3.341	0.8326	0.0612	0.800	0.041
Image/looks	FCV trial participants	3.067	0.3651	0.0667		
	High-end BEV adopters	4.697	0.5741	0.0461	<0.001***	1.630
	Low-end BEV adopters	3.043	0.9826	0.0722	0.898	−0.023
Purchase price	FCV trial participants	1.367	0.7184	0.1312		
	High-end BEV adopters	2.69	1.1709	0.094	<0.001***	1.324
	Low-end BEV adopters	2.432	1.0566	0.0777	<0.001***	1.066
Range	FCV trial participants	2.933	0.5833	0.1065		
	High-end BEV adopters	2.742	1.0497	0.0843	0.334	−0.191
	Low-end BEV adopters	1.573	0.8185	0.0602	<0.001***	−1.360
Time to refuel	FCV trial participants	2.8	0.5509	0.1006		
	High-end BEV adopters	3.148	1.4806	0.1189	0.206	0.348
	Low-end BEV adopters	2.276	1.3652	0.1004	0.039*	−0.524
Performance	FCV trial participants	3.733	0.8683	0.1585		
	High-end BEV adopters	4.897	0.4439	0.0357	<0.001***	1.163
	Low-end BEV adopters	4.178	0.8506	0.0625	0.009**	0.445
Fuel economy	FCV trial participants	3.552	0.9851	0.1829		
	High-end BEV adopters	4.974	0.2264	0.0182	<0.001***	1.423
	Low-end BEV adopters	4.919	0.4156	0.0306	<0.001***	1.367
Environmental impacts	FCV trial participants	4.828	0.3844	0.0714		
	High-end BEV adopters	4.923	0.3699	0.0297	0.209	0.075
	Low-end BEV adopters	4.903	0.3918	0.0288	0.337	0.075
Life style fit	FCV trial participants	3.077	1.1635	0.2282		
	High-end BEV adopters	4.587	0.7367	0.0592	<0.001***	1.510
	Low-end BEV adopters	3.892	0.9664	0.0711	0.002**	0.815
Running costs	FCV trial participants	3.138	1.0255	0.1904		
	High-end BEV adopters	4.774	0.5872	0.0472	<0.001***	1.636
	Low-end BEV adopters	4.865	0.44	0.0323	<0.001***	1.727

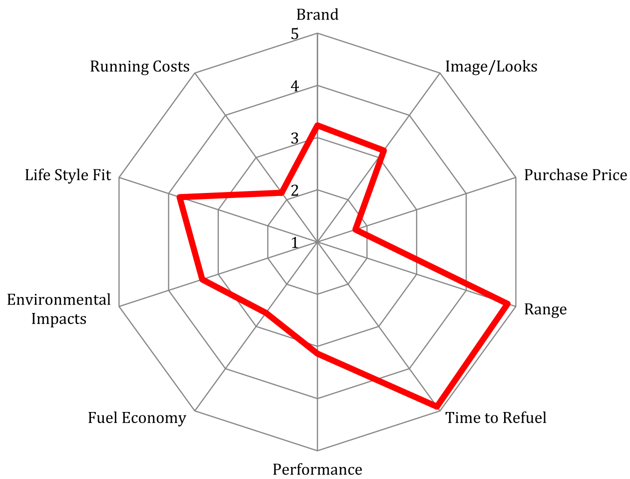

Fig. 2 – Answers to the question "Considering each of the following attributes how do you think a FCV compares to a BEV?" with answers on a Likert scale of 5 = far superior, 4 = slightly superior, 3 = similar, 2 = slightly worse, 1 = far worse.

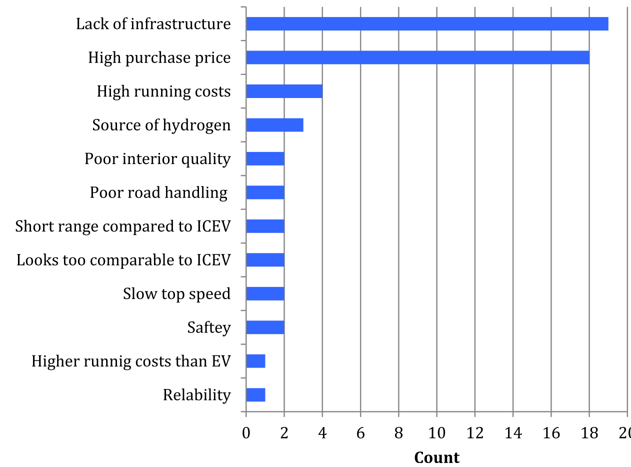

Fig. 4 – Count of responses talking about each issue when respondents were asked "What didn't you like about the fuel cell vehicle?".

Conclusion & policy implications

The unique situation that FCVs find themselves in today, which is a high priced innovation with two competing vehicle types (ICEVs & BEVs) means that their potential for market entry success is hard to anticipate. In order for consumers to adopt FCVs they must have benefits compared to both competitive vehicle types. At present FCVs are more expensive to purchase compared to an ICEV or BEV although their running costs are expected to be similar to an ICEV. Therefore the vehicles will need functional benefits so that consumers will be prepared to adopt. The results in this study suggest that FCVs have relative advantage due to their low environmental impacts, high fuel economy, performance compared to ICEVs status as high technology and the quietness of the vehicles. Therefore FCVs may appeal to environmentally, technologically or performance oriented customers who are drawn to a quiet vehicle with high fuel economy. When compared to BEVs they have relative advantage in two areas, these are the FCVs high ranges and shorter time to refuel. FCVs are perceived as having superior range compared to low and high-end BEVs which have ranges of 100 and 285 miles, respectively [14,36]. Therefore FCVs are more superior in this aspect than even BEVs with the longest ranges currently available on the market. Consumers who have adopted BEVs may be attracted to FCVs so that they can drive a vehicle with an electric drive train, which has improved range, and time to refuel compared to their current BEV.

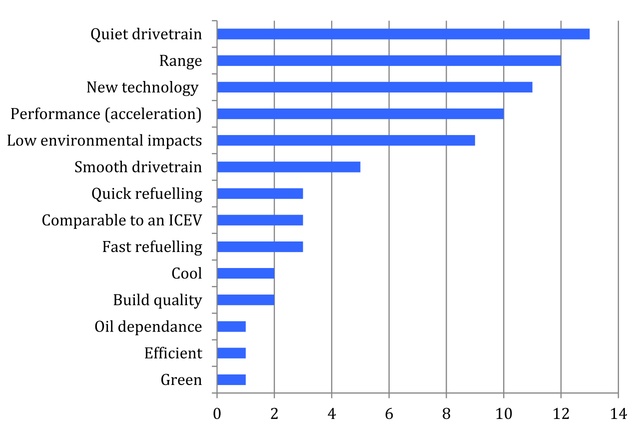

Fig. 3 – Count of responses talking about each issue when respondents were asked "What did you like about the fuel cell vehicle?".

Two significant barriers to the adoption of a FCV emerged from this study, the high purchase prices and lack of refuelling infrastructure. These two shortcomings mean that consumer intent to adopt is low with only 10% (3/30) of persons partaking in this study indicating that they would adopt a FCV. A further sample of data held by the authors that is based on in-depth interviews with BEV adopters (n = 39) found that only 8% of them would adopt a FCV. Their reasons were also related to high costs and lack of infrastructure. Another set of data, which is small (n = 9), from consumers in California who have actually adopted a FCV, indicated that of these only 3 will continue with FCV ownership in future vehicle purchases. The reasons for discontinuance in this sample is again due to lack of refuelling infrastructure, but also lack of reliability with existing refuelling stations, 6 out of 9 drivers intended to return to driving an ICEV or switch to a BEV. All of these data indicate that intent to adopt an FCV still remains low and that when adoption does occur discontinuance could be high. Action is needed in order to change this situation, and this can be done through ensuring FCVs have significant relative advantage so that consumers will be willing to adopt the vehicles despite their high costs and lack of infrastructure.

Implications for fuel cell vehicles & policy

The most significant shortcomings of FCVs that are preventative toward consumer adoption are high-costs and lack of infrastructure. Significant cost reductions would lead to FCVs gaining relative advantage if they are cheaper to purchase than an ICEV, hydrogen cost reductions would lead to low running costs being a relative advantage. Indeed BEV adopters have been found to adopt their vehicles due to running cost savings [37]. This will attract cost conscious or economically rational consumers to the vehicles. In order to achieve this, policy makers will be required to contribute to lowering the purchase prices of the vehicles. This situation already exists for BEVs and, indeed, for FCVs in many regions. In the UK £5000 is available off the purchase price of a plug-in car or £8000 for a plug-in van (this grant is also applicable to FCVs) [38]. These incentives are not enough to bring the purchase prices of the vehicles down to a lower cost compared to ICEVs, therefore larger incentives will be required. The cost of hydrogen is currently £10/kg in the United Kingdom and €10/kg in continental Europe [39,40]. The Fuel Cell and Hydrogen Joint Undertaking has the goal of reducing this cost to €5/kg, though this has not been achieved yet [40]. These figures mean the vehicles are comparable or cheaper in fuel costs than an ICEV, but more expensive to run than BEV. Policy makers will be required to increase subsidies to both purchase prices and the costs of operation so that FCVs have economic relative advantage.

The barrier of lack of refuelling infrastructure also needs to be overcame [20,35,41,42]. This was discussed in Ref. [34] where it was suggested that significant pre-development of infrastructure is needed. It is very unlikely that fuel suppliers and retailers would be motivated to finance the development of the early infrastructure because they will not receive a return on their investment due to the low number of FCVs. Therefore further investment of public money will be needed. This is the current strategy in the UK and United States where infrastructure is currently being developed at the expense of the state, with some involvement from industrial partners [43,44].

The strategy of cost reductions coupled with significant infrastructural development, will be costly to policy makers and may be undesirable to tax payers. Fortunately there is an alternative strategy that FCVs can take. Hardman et al. [45] highlighted that for FCs to enter markets they should be marketed toward niche markets. Whilst this publication explored stationary and portable power supply, the same niche market approach is possible for FCVs. A novel feature of a FCV is its ability to provide vehicle-to-home power in the event of a grid power outage or 'blackout' [46,47]. This feature is not available in an ICEV. It is possible to have this feature in a BEV, however BEVs cannot store as much energy on board compared to a FCV. The largest batteries on any BEV are 90 kWh compared to 184 kWh for a FCV[1] [14,47,48]. This would mean that power could not be provided for as long in a BEV compared to a FCV. An additional shortcoming of using a BEV in this capacity would be that if grid power is not restored the batteries would be depleted with no opportunity to recharge. A FCV could still be refuelled at a hydrogen station, providing it was operational. Therefore this could be a considerable relative advantage if sufficiently valued by consumers. This feature is not being promoted in the UK, perhaps due to the high reliability of the power grid [49]. However, it is available in the United States and Japan. In regions with unreliable grid power this feature of a FCV could convince consumers to adopt the vehicles over ICEVs or BEV. Therefore one of the early markets for FCVs may be in regions with unreliable grid power supply. OEMs should promote the vehicles first in such niche markets until some further cost reductions have been achieved and infrastructure has been sufficiently developed. Only when FCVs are able to compete with ICEVs and BEVs economically, or until they have highly valued attributes such as performance, brand or image.

Besides the rather obvious concerns about cost and infrastructure, the analysis presented here raises other questions on the competition and complementarity of FCVs and BEVs. FCVs would be preferred over a BEVs due to their range and rapid refuelling. Due to the properties of hydrogen as a fuel this is an area a BEV may not be able to compete. The gravimetric energy density of hydrogen is one and a half orders of magnitude higher than that of any known battery. This is a physical fact that will not change if current battery chemistries are used, but could change with new developments such as lithium-air batteries [50,51]. On the other hand, the energy efficiency of hydrogen fuelled FCVs will, again for physical reasons, be lower than that of a pure BEV, meaning that the operating costs are likely to remain cheaper for a BEV. Even if grid electricity became immensely expensive in the future due to a lack of fossil fuels for example, a home PV system could still provide cheap BEV charging. Therefore a basic choice has to be made between low operating costs and home recharging (BEV) and rapid refuelling as a filling station coupled with longer range (FCV).

Limitations and future research

The conclusions made in this study are limited by the fact that data is mainly quantitative and the sample size is small in comparison with some studies, but still in line with many within the literature [28,37,52,53]. In order to gain a greater understanding of consumer attitudes toward FCVs a larger quantitative or more in-depth qualitative sample is needed. A larger quantitative sample would yield results with a reduced statistical error. Clearly gathering a large sample of people with experience with an FCV would be challenging given that there are only 7 FCVs in the UK and around 180 in the USA [54]. Therefore richer data could be gathered though in-depth qualitative interviews. Indeed, the authors of this paper are currently seeking to gather such data by planning interviews with adopters of FCVs in California, with pilot data being gathered from 9 FCV adopters thus far, and researchers planning interviews with them along with other adopters in 2016. Future studies should also consider more than one FCV type, as this study only concentrated on the Hyundai IX35 FCEV. The results therefore are most relevant for this particular vehicle. However they will be indicative of perceptions toward other FCV given how consumers perceive innovations in general. Future studies should consider more than one FCV, perhaps of different body types (SUV, Sedan or Hatchback), especially as more vehicles are approaching market entry in 2016.

[1] Based on 5.6 kg hydrogen storage tanks and an energy density of 33.33 kWh/kg for gaseous hydrogen.

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