DECARBONIZATION THROUGH THE INTRODUCTION OF HYRDROGEN FUEL CELL VEHICLES IN MALAYSIA: PROSPECTS AND CHALLENGES

by Abul Quasem Al-Amin
MIT-UTM Malaysia Sustainable Cities Program
Massachusetts Institute of Technology

Abstract

Alternative energy policies targeting the adoption of hydrogen fuel cell vehicles (HFCVs) could have significant impacts on Malaysia's ability to meet both its carbon reduction goal and its energy security needs. The transport sector contributes heavily to carbon emissions. It is also difficult to decarbonize, because of the costs associated with many greener options. This study explores the possibility of decarbonizing the transport sector by promoting the use of hydrogen vehicles, and analyzes the adoption challenges and economic obstacles (especially public acceptance) to introducing HFCVs. The adoption challenges inherent in this new technology can be overcome through the use of the proper development strategies. This study also addresses the regulatory framework that Malaysia (and other countries) might use to overcome the adoption challenges of HFCVs.

Introduction

Low carbon sustainable development is a hot topic, as global warming from climate change has become accepted as a reality. The landmark Paris Accord of 2015[1] (COP21) came in the wake of mounting evidence showing that global warming is caused primarily by human activity (COP21, 2015). COP21 ended with an agreement endorsed by delegates from 195 nations to decarbonize the global economy so as to limit temperature rise to 1.5°C over the next hundred years. Among other things, COP21 called for climate action by local governments, including technology development and technology transfer.

Growing concern over global warming has motivated a great interest in alternative sources of energy. The Marrakech Proclamation of 2016 (COP22) established a framework to move the global economy to a low carbon platform by 2050 (Rasiah et al., 2017). However, this is an incredibly ambitious goal that has not been accompanied by a suitable roadmap for the development of green technology and its diffusion. The achievement of such a goal requires an unprecedented scale of innovation and technological momentum (European Parliament, 2016). Also, the countries that signed the Paris Accord are not legally bound to decarbonize their economies. A lot of uncertainty thus remains, and it is not clear how local governments will be able to implement low carbon pathways and develop and diffuse green technologies on their own (Den Elzen et al., 2016).

COP21 sought to set guidelines to promote the diffusion and transfer of technology, accounting for the financing required to develop low carbon energy equipment for the transportation, energy, and industrial sectors, as well as formulating a climate mitigation roadmap for local governments (COP21, 2015). COP21 should have done more to create a roadmap for the development of new technology to promote a more low carbon society. Unfortunately, COP21—as well as COP22 and COP23, recently held in Bonn, Germany—did not succeed in doing this.

At the Bonn meeting, delegates debated an alternative option to evaluate the applicable costs of sustainable technologies and how to diffuse them to developing countries (Bonn, 2017). The existing mechanisms and institutions would be supplemented with a "Technology Mechanism" (established in 2010 to support efforts to accelerate and enhance action on climate change), the "Technology Executive Committee" (the Technology Mechanism's policy arm) and the "Climate Technology Centre and Network" (the implementation arm of the mechanism) (Bulkeley and Newell, 2015). While the revised document produced by the Bonn meeting included support and resource transfer from developed nations to developing nations based on obligations[2], it did not consider the enhancement of domestic research and development capabilities, access to sound technology options, or support for strengthening cooperative action and collaboration among and between developing nations (Bonn, 2017). Again, this was inadequate: Sustainable development needs to focus on all aspects of technology development and deployment, including research and development, cooperation, commitment, and sustained action.

A wide range of green technologies already exist that are increasingly used to generate energy, including solar panels, windmills, biomass processors, hydrogen fuel cells, and others. Focus on the development of green technologies should not only target new sources, but also cheaper and friendlier technologies (Fridahl and Linn, 2016.). It is obvious that more collaborative negotiations would go a long way to achieving that goal (Rasiah at al., 2017). Although individual governments have submitted their Intended Nationally Determined Contributions (INDCs)[3] to the United Nations Framework Convention on Climate Change (UNFCCC), much more needs to be done to ensure that governments will introduce technologies to switch from fossil to non-fossil fuels. Policy advice can range from seeking diffusion of such fuel technologies to developing economies, to the development of entirely new sources of energy. Detailed cost-benefit analyses of various options would be enormously helpful.

Among other things, COP21 called for a green economy agenda by local governments, and suggests the pathways they should follow in providing (i) transportation, (ii) electricity and (iii) industry operations, as these three sectors contribute most heavily to carbon emissions and global warming (COP, 2015). One of the major obstacles to a green economy is that carbon emissions from upper-middle income countries are due to industrialization and rapid motorization. Carbon emissions from the transport sector in non-OECD countries are growing faster than in OECD countries (Ambrose et al., 2017).

By 2040, transportation-related energy demand will constitute 61 percent of the total demand in non-OECD countries (EIA, 2017). Developing countries not only need to meet carbon emissions reduction goals, but also motorization demand. A number of countries are looking for a sustainable framework with viable options for cleaner fuel, energy security, and technology to reduce carbon emissions in line with the Paris agreement. Many recent contributions to the scientific literature have addressed those issues, and attention has been given to the importance of cleaner fuel, energy security and alternative technological intervention (Emonts et al., 2017; Preuster et al., 2016; Singh et al., 2015; Silva et al., 2014; and Bae & Cho, 2010).

In light of this, a move to a lower carbon society may require alternative, non carbon-based technologies. This will not be an easy task as long as conventional fuel cell vehicles dominate the worldwide transportation sector. The achievement of low carbon innovation therefore needs both clean energy transition policies and technological momentum. Widespread sustainable development and green motorization can only occur when the following key queries are answered:

1. How should the low carbon society be framed, and what its function within the scope of sustainable city roadmap;
2. How is a low carbon society possible, given the existing challenges; and
3. Currently, how many alternatives are there?

Malaysia's concerns around these issues mirrors those in other advanced and transitional economies. Malaysia is committed to a 45 percent reduction in per capita carbon emissions by 2030 (low carbon pathways) based on 2005 levels, as declared at the Paris Accord. Carbon emissions must be reduced substantially to meet the 2030 target (Rasiah et al, 2017). Accordingly, Malaysia not only needs to address an increasing demand for cars, but also the carbon reduction goal it announced in Paris. How should Malaysia consider a green pathway with alternative technologies? Progress has been made with alternative technologies such as plug-in electric and hybrid vehicles; however, there are a number of shortcomings associated with these technologies. Specifically, there are a number of performance concerns for hybrid vehicles, such as less power and acceleration (Ambrose et al., 2017). This is due to their smaller engines, which maximize engine efficiency. Hybrid vehicles are made with lighter-duty components, which provide less support in the suspension system in comparison to conventional vehicles. Moreover, maintenance of the dual compulsion engine systems is expensive. Overall, hybrids' mechanical proficiency and performance is less than conventional vehicles.

Comparatively, plug-in electric vehicles also have a number of concerns, such as shorter driving distance due to battery limitations (Manthiram, 2016). The average distance that can be traveled by plug-in electric vehicles is about 160-200 kilometers. Vehicles that can travel farther distances—up to, say, 450 kilometers—are costly. Plug-in electric vehicles also take a long time to recharge, compared to simply filling up with conventional fuel. One potential alternative is a shift to hydrogen fuel cell vehicle (HFCV)[4] transport systems. This would address the challenges of power, output, and battery constraints faced by plug-in electric and hybrid vehicles. Moreover, HFCVs are emission-free—an advantage over plug-in electric, hybrid, and conventional fuel vehicles that rely on fossil fuels.

Recent studies show that Malaysia could reduce its carbon emissions by up to 26 mtoe (million tons of oil equivalent) by substituting 50 percent of existing conventional vehicles with hydrogen fuel cell vehicles (Ambrose et al., 2017). It is thus important for policy makers to think about the hydrogen fuel cell option in Malaysia. However, widespread adoption of HFCVs in Malaysia presents challenges in three broad areas:

- cost
- technology, and
- public preference

Currently, there are no HFCVs available in Malaysia. Before they can be introduced, issues such as infrastructure, regulatory frameworks and safety standards, subsidy/incentive options, affordability, capacity and support systems, and strategies for replacing conventional vehicles need to be in place. In terms of technology, many innovation and R&D-related issues remain, particularly cost of production, cost of membrane, mass production, a cheaper component for the catalyst, cheaper energy conversion, safety, market-based competition, and public awareness programs required to adapt to new technology. HFCVs require careful consideration of macroeconomic issues, economic obstacles, and the likelihood of acceptance of new technologies, with risks and uncertainties taken into account. This study addresses public preferences toward HFCVs from the viewpoints of stakeholders, policymakers, and society, in an effort to understand the technology-adoption challenges and barriers of introducing HFCV in the transport sector in Malaysia. This poses the following key sub-questions:

- What are the economic obstacles that affect public acceptance of new technology and public preference towards shifting to HFCVs?
- What are the environmental and macroeconomic impacts of introducing HFCVs to meet Malaysia's 2030 Paris Accord target?

The conventional transportation system and its correlating energy demand are expected to continue unless a sustained intervention takes place. Thus, the key concern should be how to simultaneously promote economic growth and a clean energy transition.

Hydrogen fuel cell vehicles: A review

Based on the relevant literature, it is clear that increased emissions due to consumption of conventional fuel is causing environmental degradation (Akhatar et al. 2014; Andres et al, 2012; Gutiérrez and Méndez, 2012; Timilsina and Shrestha, 2009; Hensher, 2008). However, an effective transportation system is a central part of economic development, and cannot be hobbled in the name of sustainability. Fossil fuels are presently the major source of energy for Malaysia's transportation system. Numerous studies have raised concerns over the environmental sustainability of this approach, and suggest options with alternative energy sources (Timilsina and Shrestha, 2009; Maclean, 2004; Bonnafous and Raux, 2003). The concept of a greener economic system has been around for a long time; however, the principle of working toward low carbon and smart transport options is still new. Questions remain over how to minimize costs for low carbon and smart transport systems, and which strategies are essential to decarbonize the national economy to achieve a greener low carbon society that addresses economic realities[5] and societal needs (Ekins, 2010).

Studies by Emonts et al., (2017), Ambrose et al., 2017; Preuster et al., (2016), Singh et al., (2015), Silva et al., (2014), and Bae & Cho (2010) indicate the importance of alternative technological intervention based on the hydrogen fuel cell economy, vehicles, and transport system. Given the lack of workable alternatives, it is time for the transportation sector to commit to the replacement of combustive engines (Eberle, Müller & von Helmolt, 2012; Cropper, Geiger & Jollie, 2004). Policymakers must commit to developing an economically viable energy infrastructure that can support sustainable transport systems based on hydrogen power (Ambrose et al., 2017). For example, there are still challenges related to technological constraints, electrical energy storage, and zero-emission targets that must be addressed in order to replace conventional fossil fuels (Ambrose et al., 2017; Ahmed et al., 2016).

The lessons learned from the introduction and adoption of electric vehicles (EVs)—challenges like technology, infrastructure, vehicle performance, price, and cost to end user (Raslavičius, et al., (2015), Hannan et al., (2014), Narayanan et al., (2012), Whittingham, (2008))—may suggest the way forward for emissions-free HFCVs.

Choosing a sustainable transport pathway will be crucial for Malaysia as it seeks to meet demand for cars and at the same time avoid a massive rise in emissions. Today, Malaysia offers compelling example of a developing country meeting its INDC (Figure 1, World Bank, 2016).

But the country is expected to increase conventional transport, with the per capita vehicle ownership growth rate at 5.9 percent annually (Figure 2) (Economic Planning Unit, 2015). A study on the technology roadmap for HFCVs by IEA (2015) indicated that 150 million HFCV sales are expected globally by 2050 to reduce fossil fuel dependence and contribute to energy security. Although HFCV technology is relatively far advanced, other factors—such as overcoming public misconceptions about HFCV technology, infrastructure, regulatory framework, energy prices, technological development, economic challenges, cost-to-user public perception, and possible socio-cultural obstacles of adopting HFCVs—are still a concern (Ambrose et al., 2017).

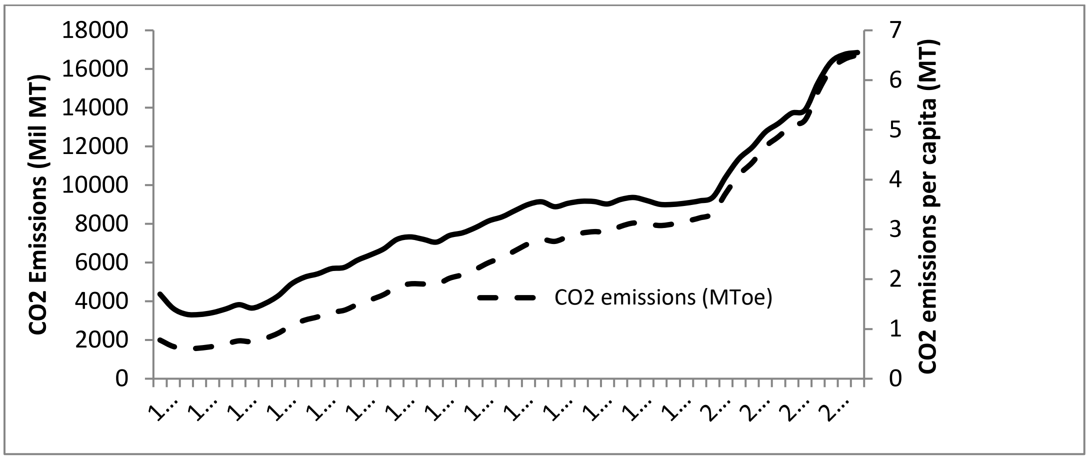

Figure 1: CO2 Emission of Upper Middle Income Countries, 1960–2012[6]

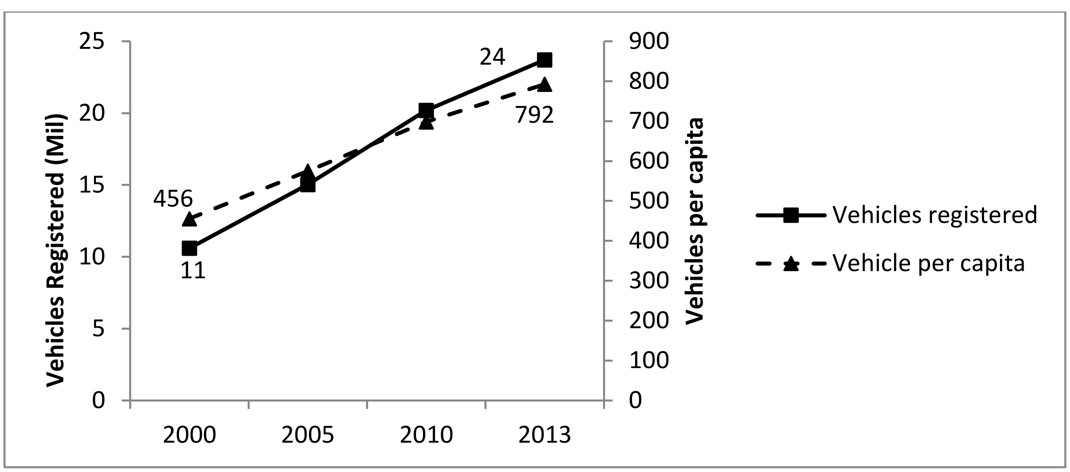

Figure 2: Vehicles registered and vehicles per capita for Malaysia, 2000−2013[7]

It is obvious that public purchase intentions, attitudes, purchase behaviors, and acceptance greatly vary depending on a country's position, economic development, and comparative advantage, all of which influence consumers (Chen et al., 2016; Albayrak et al., 2013; Barber et al., 2012). Some earlier studies have addressed public acceptance and attitudes (Altmann, et al, 2003; Dinse, 2000; Dinse, 1999); however, those studies did not address the scope of attitudinal research on purchase intentions or purchase behaviors, and how intended use influences certain behaviors or perceived behavioral control (e.g. perception of impact)[8] (Albayrak et al., 2013; Axsen, et al., 2013; Barber et al., 2012). Purchase behavior mostly depends on customer satisfaction, as addressed by the studies of Barber et al. (2012), Wang et al. (2000) and Stobart (1999). Three attitudinal variables—purchase behavior, environmental consequences, and perceived risks and individual preferences for new innovation—are commonly connected to public preference. Some studies also indicate that the purpose of intention and role of attitudes to the purchase intention depends on the meaning of attitudes, perceived behavioral control, and subjective norms (Ambrose et al., 2017). The skepticism on risks may not be disadvantageous for HFCV to be successful in the market penetration; however a perceived risk performance, safety concerns and pathways may potentially impact public acceptance (Axsen, J., and Kurani, K.S. 2013).

Without doubt, HFCV is a new area that requires much study specific to the Malaysian context. This study seeks to make an initial contribution to such initiatives by looking at the prospects and challenges associated with a shift to HFCVs in Malaysia.

Methodological approach

This study adopts a "policy strategy" scope that uses survey-based techniques. The policy strategy uses quantitative Structural Equation Modeling (SEM) to explore implications of strategies and economic obstacles to public acceptance of hydrogen fuel cell vehicles (HFCVs) with public preferences. Methodological steps include (a) research hypotheses, (a) study area, (c) data sources and sampling technique, and (d) questionnaire design, including model fitness, to find the study goals.

Research hypotheses

This study considered five hypotheses for understanding the scope of a sustainable city roadmap toward a low carbon society by introducing HFCVs. The proposed hypotheses—which identify relationships within the selected study variables, and obtain the research outcomes on HFCV concerns—are as follows:

- H1 Awareness (AWAR) has a positive impact on values
- H2 Environmental knowledge (KNW) has a positive impact on awareness (AWAR)
- H3 Values have a positive impact on environmental knowledge (KNW)
- H4 Awareness (AWAR) has a positive impact on behavior (BEHAV), and
- H5 There is a positive relationship between behavior (BEHAV) and environmental knowledge (KNW) for the purchase intention (PI)

Study area

This study considered Putrajaya (the administrative capital of Malaysia), Kuala Lumpur, and its associated territories to identify economic obstacles to public acceptance of new technologies. These areas are some of the largest in Malaysia in terms of gross domestic product (GDP) and population (DOS, 2017). Maps of Putrajaya and the Kuala Lumpur region are shown in Figure 3.

Data sources and sampling technique D

Primary data was collected from structured and semi-structured interviews held between October 2017 and January 2018. For the structured surveys, 300 written questionnaires were distributed to existing vehicle owners in age categories of 18−30, 31−45, 46−60, and 61 and above. The semi-structured surveys were conducted through face-to-face interviews with an average duration of 50−55 minutes. Of the total 338 questionnaires that were distributed, 232 were completed. There were 48 questionnaires that were not completed fully and 58 that were not filled out correctly. The overall success rates for the structured and semi-structured survey were about 67 percent and 84 percent, respectively.

Questionnaire design

The structured questionnaire consisted of two sections. Section A asked about respondents' socio-economic characteristics: gender, age group, race, education, and monthly income. Section B asked about respondents’ environmental values and related subject matters, such as environmental concerns based on moral and ethics, attitudes, environmental knowledge, awareness, purchase intention, purchased behavior, environmentally friendly brands, quality, safety, design, subjective norm, uses of alternative fuel performance, and preference among environment-friendly cars in Malaysia. Most questions in section B are measured using 5-point Likert scales, representing a range between (5) strongly agree and (1) strongly disagree. Semi-structured surveys observed the social value related/ individual preference and challenge/obstacle of respondents to buy/use an environmental friendly vehicle/HFCV to support a low carbon society in Malaysia. The scope of issues covered in the semi-structured interviews comprised environmental sustainability, challenges, infrastructure development issues, economic obstacles, non-technology or non-cost factors, and types of support required directly and indirectly from policy makers or government.

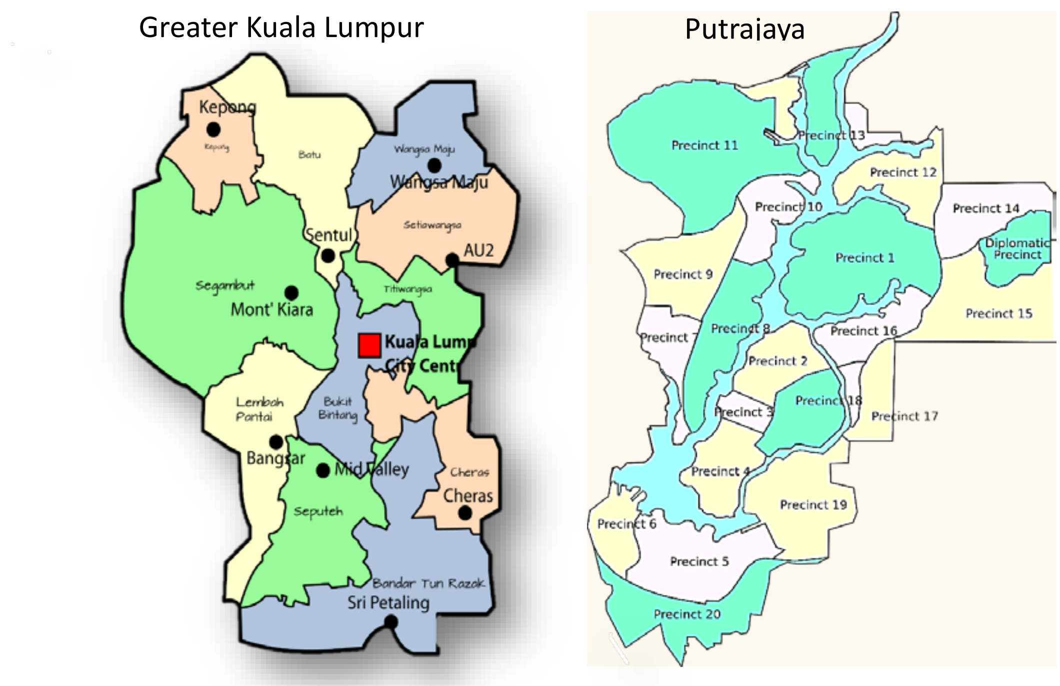

Figure 3. Maps of Putrajaya and Kuala Lumpur regions of Malaysia

Results and discussion

Descriptive statistical analysis

As noted, this study draws upon 232 completed structured and semi-structured questionnaires, with a response rate of over 75.5 percent. Respondents were 51.7 percent male and 48.3 female. The ethnic backgrounds of respondents were 13.4 percent Malay, 27.2 percent Indian, 55.6 percent Chinese, and 3.9 percent other. The majority of respondents were between 31 and 45 years old. 28.9 percent held graduate degrees, followed by 19.4 percent with undergraduate diplomas, 18.5 percent who had completed lower secondary school, 18.1 percent who had completed higher secondary school, 6.5 percent with post-graduate degrees, and 4.3 percent with primary education or no formal education, respectively. In terms of income, the respondents' largest income group was RM2001−4000 (40.1 percent), followed by RM4001−6000 (37.1 percent) (Table 1).

Variables	**Frequency**	**Percentage (%)**
Gender		
Male	120	51.7
Female	112	48.3
Age		
18−30 years	81	34.9
31−45 years	113	48.7
46−60 years	32	13.8
61 years and above	6	2.6
Race		
Malay	31	13.4
Indian	63	27.2
Chinese	129	55.6
Others	9	3.9
Education		
No formal education	0	0
Lower secondary school	63	27.1
Higher secondary school	42	18.1
Diploma	45	19.4
Graduate	67	28.9
Post graduate	15	6.5
Income		

RM 2000 or less	19	8.2
RM 2,001−RM 4,000	93	40.1
RM 4,001−RM 6,000	86	37.1
RM 6,001−RM 8,000	18	7.8
RM 8,001 and above	16	6.9

Table 1. Breakdown of respondents' demographic information (*N=232*)

Environmental values, knowledge, and awareness

The level of environmental awareness, as defined by several indicators, is addressed to measure respondents' understanding. The results show that 47.8 percent of respondents are aware of environmental matters, and 38.8 percent of respondents understand that a clean environment is important for all. 40.9 percent of respondents believe that use of conventional vehicles creates greater dependency on conventional fuels. 40.1 percent of respondents indicate that clean transportation is important to overcome existing air pollution caused by conventional transport (Table 2). 75 percent of respondents support the idea that an alternative energy system can help to reduce air pollution in urban areas. 67.7 percent of respondents believe that HFCVs, compared to conventional vehicles, can help with overall environmental sustainability.

Awareness of environmental subject matters

The results identify that respondents have some degree of awareness related to HFCVs' cost, safety, performance, appealing design, and comfort. Specifically, 61.2 percent would buy a HFCV if the cost were equivalent to a conventional vehicle, 56.5 percent would buy a HFCV if it were safer than a conventional vehicle, 56.9 percent would buy a HFCV if the performance were weaker than a conventional vehicle, 60.8 percent would buy a HFCV if it had a less appealing design, and 68.5 percent would buy a HFCV even if it were less comfortable (Table 3).

Item(s)	**Frequency**	**Percentage (%)**
Clean and tidy environment is important to me	111	47.8
Conventional vehicle creates air pollution	90	38.8
Conventional vehicle creates smog in cities	95	40.9
Conventional vehicle creates greenhouse gases (GHG) such as CO_2, NO_x, and N_2O that contribute to global warming and climate	93	40.1

change		
Alternative energy system can help to reduce air pollution in urban areas	95	75.0
HFCVs can help with overall environmental sustainability	89	67.7

Table 2. Values and environmental knowledge

Item(s)	**Frequency**	**Percentage (%)**	**Cumulative Percentage* (%)**
I would buy HFCV if the cost were equivalent to a conventional vehicle	70	30.2	61.2
I would buy HFCV if it were safer than a conventional vehicle	69	29.7	56.5
I would buy HFCV even if the performance were weaker than a conventional vehicle	67	28.9	56.9
I would buy HFCV even if it had a less appealing design	70	30.2	60.9
I would buy HFCV even if it were less comfortable	77	33.2	68.5

**Cumulative percentage calculates the percentage of the cumulative frequency within each interval*

Table 3. Factors affecting HFCV purchase intentions

Purchase intention and awareness of HFCV

As stated above, this study has considered five hypotheses that have been tested to understand consumers' purchase intentions. According to results, all five hypotheses were supported. Hypothesis H1 (awareness has a positive impact on values) finds that there is a positive relationship between AWAR and values with coefficient[9] of 0.312. It shows that awareness and personal values influence intention to purchase HFCV at the significant level of 1 percent. Hypothesis H2 (knowledge has a positive impact on awareness) finds that there is a positive relationship between KNW and AWAR with the coefficient of 0.241. This suggests that knowledge of environmental sustainability and awareness of environmetal issues are closely related to having a positive purchase intention for HFCV. Hypothesis H3 (values have a positive impact on environmental knowledge) finds the positive relationship between KNW and values with the coefficient of 0.564, and these values are more influencial than those between KNW and AWAR. This shows that personal values are very important if there is awareness of environmental sustainability. Hypothesis H4 (awareness has a positive impact on behavior) finds that there is a positive relationship between BEHAV and AWAR, with the coefficient of 0.087 at the significant level of 1 percent. It specifies that awareness of environmental sustainability influences purchase behavior for HFCV. Finally, hypothesis H5 (there is a positive relationship between behavior and knowledge) finds that there is a positive relationship between BEHAV and KNW with the coefficient of 0.709 at the significant level of 10 percent. This means awareness of HFCV and knowledge of environmental issues play a significant role in influencing purchase behavior (Table 4). These results are supported by related studies performed by Kline (2010) and Schumacker & Lomax (2004).

There are several key points found for purchase intention (PI) and purchase behavior (PB) in the study model, which are associated with AWAR and values, KNW and AWAR, and BEHAV & KNW (Figure 4). The study found a significant relationship between personal values and awareness of HFCV, due to the knowledge that conventional vehicles create air pollution and conventional vehicles depend on conventional fuels, as shown by e1 ($\beta = 0.56$), e2 ($\beta = 0.10$) and e3 ($\beta = 0.46$). Additionally, knowledge of environmental values plays a significant role in influencing purchase behavior, through the knowledge that conventional vehicles create greater dependency on conventional fuels that cause greenhouse gas emissions, as shown by e3 ($\beta = 0.71$), e1 ($\beta = 0.56$), and e2 ($\beta = 0.24$).

No	Hypotheses	Coefficient (β)	Remark
H1	AWAR<--- Values	0.312	Supported
H2	KNW <---AWAR	0.241	Supported
H3	KNW<--- Values	0.564	Supported
H4	BEHAV<---AWAR	0.087	Supported
H5	BEHAV<---KNW	0.709	Supported

Table 4. Path coefficients of purchase intention hypotheses

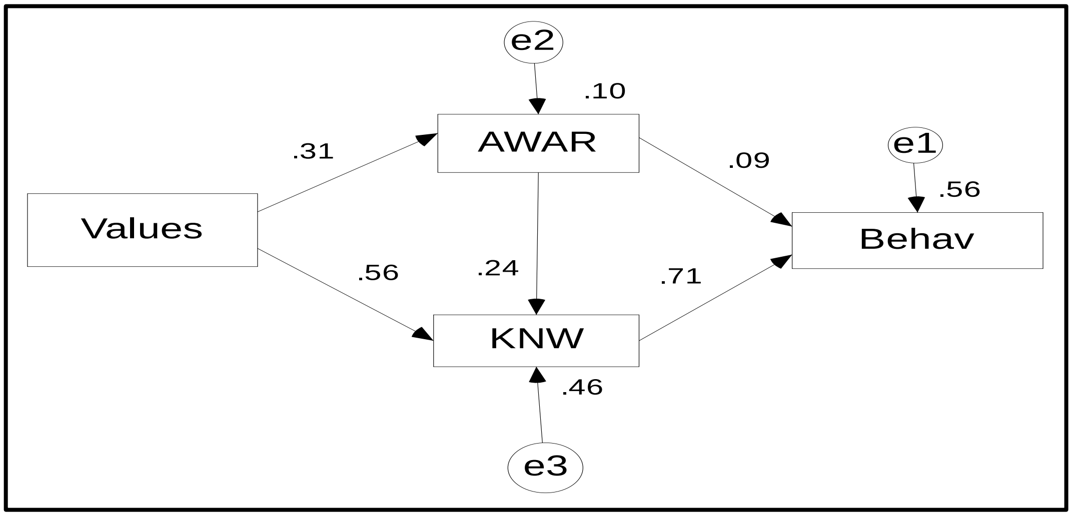

Figure 4. Relationships between purchase intention and awareness

Discussion and policy implications

Hydrogen energy is expected to play an important role in future energy infrastructures. This expectation has come true in many of the developed countries that replaced a portion of their conventional energy with alternative fuels. As Malaysia considers how to replace its conventional energy, options for its future direction includes an emission-free hydrogen-based transport system. While a gradual shift to hydrogen transportation is under consideration, concerns remain over how to make such a transition, including how to implement a support system that can enable this transition.

This study first employed the Theory of Planned Behaviour model (TPB: Ajzen, 2002) with several components—such as environmental knowledge, environmental attitude toward HFCV, awareness of HFCV, purchase intention and purchase behaviour toward HFCV—used to consider these concerns. Second, the study explored infrastructure development issues, to understand on how such a transition can be implemented and sustained.

HFCV implementation issues in Malaysia comprise several fronts. This study categorizes them into three broad aspects:

- technology adoption and economic obstacles
- public acceptance of new technology and public preference, and
- managing (reach) a sustainable low carbon society target

Technology-adoption challenges include safety standards, user costs, vehicle mileage, and issues related to public acceptance of and preferences regarding HFCVs. Economic obstacles involve resources, capacity, and support systems for HFCVs.

To suggest possible ways of addressing these implementation challenges, this study considered how market demand for HFCVs can be increased. Toward that end, the following outcomes have been used:

- environmental values, knowledge, and awareness,
- awareness of environmental subject matters,
- purchase intention and awareness, and
- purchase behavior responsiveness towards a low-carbon society by introducing hydrogen-fuel-cell vehicles

The hypotheses' tests indicate that people decisively believe that HFCVs (compared to conventional vehicles) can help with overall environmental sustainability. Threshold values of all tests on first mediator of e1 (β = 0.56), e2 (β = 0.10) and e3 (β = 0.46) and second mediator on e3 (β = 0.71), e1 (β = 0.56), and e2 (β = 0.24) confirm that knowledge plays a significant role in influencing purchase behavior. This study offers some recommendations based on those observations that can help to transform such strategy choices into actions.

The introduction of HFCVs in Malaysia must be addressed by both demand side[10] and supply side[11] policies, as illustrated in Figure 5. Ultimately, equilibrium should be the goal in policy strategy, where both sides' policies are coordinated in the same direction and meet at the same place. To reach equilibrium, demand side policies should focus on purchase intention issues. Policy strategy should have the benefit of in-depth knowledge concerning the direction of perception intention and the quantification of awareness behavior. Proper management of negative public attitudes and acceptance is important for successful introduction of HFCVs. Consumers' concerns about the environment may not necessarily translate into a greater likelihood of purchasing a cleaner vehicle like a HFCV. Roche et al. (2010) acknowledged consumers' concerns and environment, and intensified demands of consumers for introduction of HFCVs. Earlier, Heffner & Turrentine (2007) addressed consumers' concerns and environmental issues, and emphasized how important consumer environmental behavior and concerns are in shaping green technology preferences.

In contrast, supply side policies should focus on innovation and techno-economic obstacles, R&D and commercialization, as those may be weighed down by uncertainties and safety concerns.

Policymakers must shape the conditions that create the scope of both demand and supply side options for HFCVs. The demand side options should be intensified to create market demand for HFCVs that address the correlation of mediating effects on purchase intention, awareness, and gaps of public acceptance, recognition, preference, subjective norms, perceived behavior control, and attitude towards HFCVs. This study's outcomes by correlation valuation, public preference, and perceived behavioral issues could serve as a basis for strategy selections into actions. The study outcomes can help inform demand side strategy and create the scope for a supply side plan. However, such as the demand side options cannot work unless there is a check-and-balance effect exerted by the supply side options.

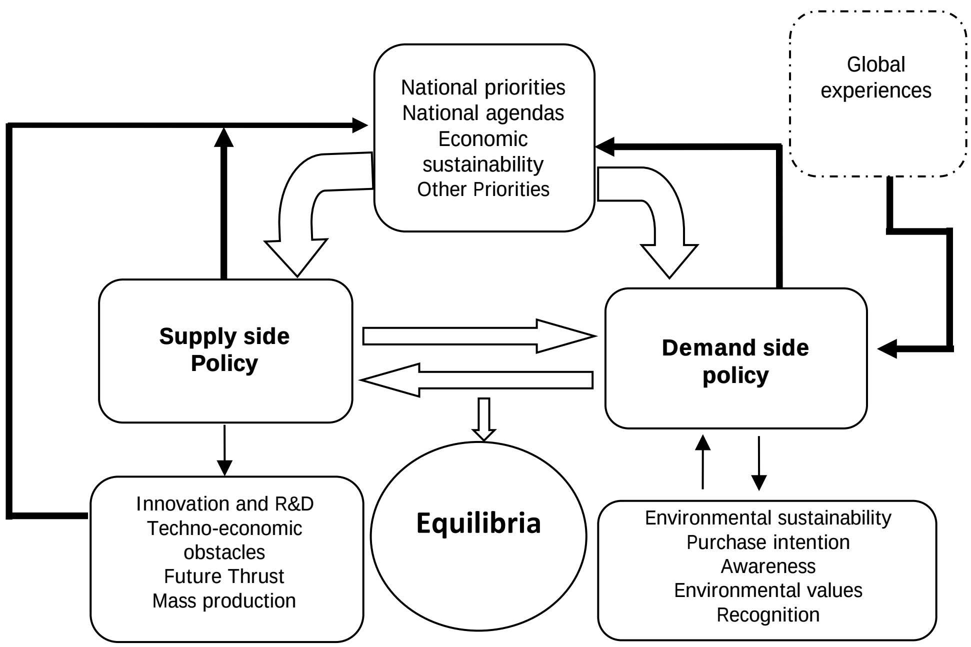

Figure 5: Demand side and supply side policy coordination

Thus, policy guidance on hydrogen fuel cell vehicle implementation should be issued from top to bottom, as indicated in Figure 6. First, it should consider Malaysia's national low carbon pathways as starting points, where sustainable transport can support the national agenda for economic and environmental considerations. Second, national energy security concerns about conventional energy resources will come in play, with technology options to support alternative energy resource in national plans and roadmap. Finally, HFCVs's level of adoption will progress to meet milestones agreed upon for the goals of Paris 2015 and Malaysia's Low Carbon Pathways 2030.

The policy direction around HFCV adoption should be formulated with both public and private support. It should be noted that not all communities can afford a new technology unless a sustained affordability strategy is made available to the consumer. Gordon et al. (2012), in addressing policy priorities for advancing the U.S. electric vehicle market, state that effective policymaking must involve consultations with various stakeholders, including carmakers. The lesson learned can be a good way forward for the case of HFCVs in Malaysia. There are two elements of concern that are to be solved:

- Affordability: compared to developed countries, how can consumers in developing countries like Malaysia afford HFCVs?
- Adaptability: developing countries with limited capacity may turn to alternative options such as climate finance, which require an international negotiation

The national HFCV implementation roadmap in Malaysia should be structured so that (i) technology adoption challenges and economic obstacles and (ii) obstacles of public acceptance for a new technology and public preference would emerge through likely technology developments over time (Figure 6). The 2030 timeframe is reasonable to potentially have HFCVs in the market. However, the policy approach would invoke energy security and alternative renewable energy resources, with the goal of finding an optimal adaptive level of technology for future. This approach will support adoption of HFCVs in the long term. Even if there is no direct subsidy from the government, if the technology is at least available in the market and enough resources are in place to support HFCV implementation, finding the point of equilibrium should be possible. Once the technology is commercially available and mass production in place, the problems of both technology adoption and economic obstacles, and public acceptance and preferences, will be minimized.

Second, existing national plans for low carbon pathways and the country's plans for fulfilling its Paris Accord commitments can address the need for greater resources towards implementing HFCVs. Future national actions must include growth targets, short and long run plans, action schemes, infrastructure development strategies, likely support mechanisms, regulatory frameworks, and safety standards.

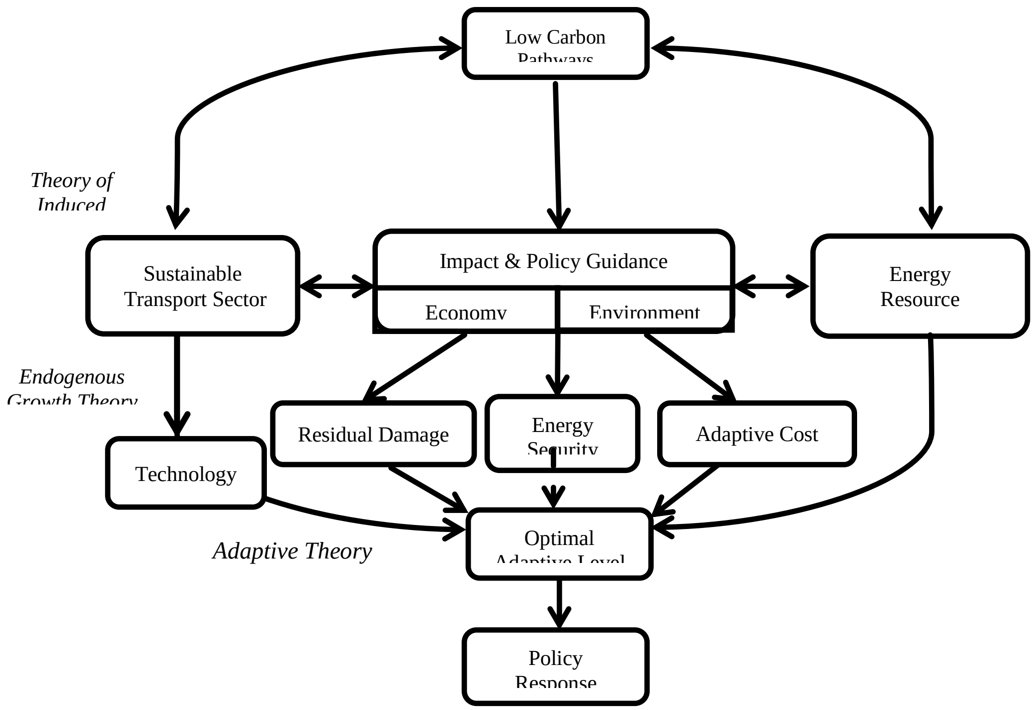

Figure 6: Suggested policy intervention and its relations to the Malaysian economy

The government of the East Malaysian state of Sarawak has launched a pilot project to introduce HFCVs as a form of sustainable transport. However, no national-level blueprint exists to map out strategies for achieving the low carbon milestones laid out by the goals of the Paris Accord. Nor is there a roadmap to resolve the challenges of regulatory framework, safety standards, infrastructure development strategies, visions of viability, and direct support mechanisms. Therefore, a regulatory framework with public and private support is needed to address current gaps, ranging from technological innovation to optimal adaptive level. This study used both behavioral and policy approaches to find a likely equilibrium between the low carbon pathways and policy responses, as shown in Figure 6.

In summary, this study found that purchase intention and purchase behavior towards HFCVs are closely associated with environmental awareness and values (β=0.312), environmental knowledge and awareness (β=0.241), and purchase behavior and environmental knowledge (β=0.709), which confirm this stud's hypotheses. However, environmental knowledge plays a more significant role in influencing purchase behavior through awareness, as shown by e3 (β = 0.71), e1 (β = 0.56), and e2 (β = 0.24). Therefore, it is particularly important to consider policy options from the demand side as the first phase of action. For example, to maximize the impact of environmentalism on purchase behavior, demand side policy should be incentivized initially to create the market demand for HFCVs. Once the demand for HFCVs is established, it will create the opening for supply, and eventually both demand and supply will create simultaneously market conditions that will support adoption of HFCVs.

The federal government's role is very important in leading adoption of a new technology like HFCVs, where much support and effort are initially required, and the demand and supply side policies need to be strategically coordinated (Figure 5). The government should incentivize demand side components—such as purchase rebate, tax credit, sales tax waiver, registration fee reduction, low carbon fuel policy, and environmental awareness—and should showcase states leading on low-carbon HFCV, transition to transportation carbon pricing, and zero-emission vehicle mandates for a substantial period of time. Which incentives to use will depend on how quickly the costs of HFCVs decline. Selecting incentivizing options may depend on how consumers respond to non-monetary and monetary incentives, which can vary by demographics as indicated (Table 1). The policy maker must also propel supply side policies by developing a national plan, motivating HFCV manufacturers, extending HFCV policies to encourage industry support, providing import duty waivers and discount on raw materials, creating a national hydrogen blueprint that phases out conventional vehicles, and providing support for infrastructure development.

Conclusion

This study addresses the prospects and challenges of introducing hydrogen fuel cell vehicles in Malaysia by focusing on the goal to reduce per capita carbon emissions by 45 percent (compared to 2005 levels) by 2030. To meet this goal, a substantial amount of carbon emissions must be eliminated from the country's transport sector. A key question is how Malaysia can incorporate alternative greener technology such as HFCV as it maps low carbon pathways for its future. Thus, policy recommendations for implementing HFCVs suggest managing demand and supply side polices that simultaneously follow low carbon pathways and other national sustainability agendas.

To select policy actions, this study tests the likely challenges to HFCV implementation with several related factors. It finds all factors, particularly environmetal awareness toward values ($\beta = 0.31$), environmetal knowledge toward awareness ($\beta = 0.24$), values toward environmetal knowledge ($\beta = 0.56$), behavior toward environmetal awareness ($\beta = 0.087$), and behavior toward environmental knowledge ($\beta = 0.71$), have a positive and significant impact to favor HFCV. Those factors are categorized as components of demand side policies. In contrast, technology, mass production, R&D, cost of production, safety, subsidy issue, regulatory framework, and future thrust are components of supply side policies. The overall policy suggestions stress that a market-driven option will be effective in promoting HFCVs in Malaysia over the long run; however, in the short run, however, some degree of intervention by policy makers is required to outweigh macroeconomic deterrents and motivate consumer demand. Such interventions might include: motivating consumers and HFCV manufacturers, public support for relevant research and development, disincentives for conventional vehicle and incentives supporting HFCVs, increased awareness of the low-carbon path, transition to conventional transportation carbon pricing, registration fee reduction, low carbon fuel policy, showcasing of states leading on low-carbon HFCVs, and phasing out of conventional vehicles gradually, through regulation. Finally, long-term planning will be essential for the Malaysian government as it seeks to accelerate the transition to low carbon pathways and decarbonize its economy through the introduction of hydrogen fuel cell vehicles. This study considers the Malaysian context as a case study; nevertheless, these policy suggestions can potentially help in other settings where emissions from the transport sector are huge and new energy options are a fundamental concern.

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Appendix

Validation of measurement model

Validation is important to determining the study outcomes, as some hidden variables can affect findings as addressed by some studies (Kline, 2010; Hair et al. 2011). Thus, some measurements such as Absolute Fit Index (e.g. RMR and GFI), Incremental Fit Index (e.g. CFI and NFI), and Parsimony Fit Index (e.g. χ2/df) have been tested. The fit indices show that the model fits the data. The normed chi-square χ2/df =1.00 is below the recommended cut-off point of 5 to reflect good model fit. Also, CFI of 0.873 and RMR 0.038 indicate that the data fit the model well (Byrne, 2013; Hair et al., 2010). The model-fit indices for the model were statistically significant at the .001% level, and the relative recommended thresholds presented well. The values of GFI (0.901) and NFI (0.892) were very close to threshold value. The model-fit indices' results are summarized in Table 1A. The model summary, as indicated in Table 4, shows a presence of absolute, incremental, and parsimony fit. The results supported by the related studies indicated by Hair et al (2010) and Chinna (2009).

Model Fit Indices	Threshold Value	Observed value for The Measurement Model
Absolute Fit Index		
RMR	≤ 0.10	0.038
GFI	≥ 0.90	0.908
Incremental Fit Index:		
CFI	≥ 0.90	0.900
NFI	≥ 0.90	0.900
Parsimony Fit Index		
χ^2/df	≤ 5.0	1.000

Table 1A. Fitness of research model

Nomenclature (abbreviations)

AWAR Awareness
BEHAV Behavior

COP	Conference on Climate Change
EIA	Energy Information Administration (United States)
EV	Electric vehicles
GHG	Greenhouse Gases
HFCV	Hydrogen Fuel Cell Vehicles
INDCs	Intended Nationally Determined Contributions
KNW	Knowledge
OECD	Organization for Economic Co-operation and Development
PB	Purchase behavior
PI	Purchase intention
R&D	Research and Development
SEM	Structural Equation Modeling
SN	Subjective Norms
TPB	Theory of Planned Behavior
UNFCCC	United Nations Framework Convention on Climate Change

Notes

[1] This grew out of the United Nations Conference on Climate Change (COP) in 2015, held since 1995 under the framework of the United Nations Framework Convention on Climate Change (UNFCCC).
[2] The obligations included the Paris Agreement's agenda on global response to climate change beyond 2020 and pre-2020 commitments and actions, differentiated responsibilities and Parties' (i.e. nations signed for an accord) efforts to cover adaptation, mitigation and means of implementation addressing new technology framework, including its guidance to the technology mechanism in enhancing global actions.
[3] Intended Nationally Determined Contributions (INDCs) is a commitment by counties who signed the Paris Agreement, under UNFCCC for reductions in greenhouse gas emissions to a certain level over time.
[4] A conventional vehicle is that uses an internal combustion engine in which combustion of fuel (usually petrol and diesel) generates by-products of greenhouse gases (GHG). Unlike conventional vehicles, hydrogen fuel cell vehicle's technology combines oxygen and hydrogen to generate electricity to power an electric motor. They operate much like electric vehicles (EVs), but they differ substantially in their refueling, procedure, and conversion processes.
[5] Obstacle/issue is that a development which connects with technology and societal needs, unsure that market forces (e.g. prices) may not be achieved for the society unless further technological interventions take place.
[6] World Bank, 2016
[7] Economic Planning Unit, 2015
[8] Benefit intention on the awareness on the environment may influence consumer purchase intention. Once enough people understand the benefit of HFCV for the environment, then the purchase intention of consumers may influence in support of HFCV (Chen et al., 2016; Albayrak et al., 2013).
[9] The coefficient (r) measures the direction and strength of a linear relationship between two variables (Y=ax+b) within the valued range of between +1 and –1.
[10] Demand side policies aim to increase aggregate demand (AD) in the economy through either contractionary or expansionary policies. Those polices are related to aggregate spending in the overall economy based on the economic situation.
[11] Supply side policies aim to increasing aggregate supply (AS) in the economy through productive capacities by improving the factor of production.