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Portfolio analysis of alternative fuel vehicles considering technological advancement, energy security and policy

Kamila Romejko*, Masaru Nakano

The Graduate School of System Design and Management, Keio University, Kyosei Building, 4-1-1, Hiyoshi, Kohoku-ku, Yokohama, Kanagawa, 223-8526, Japan

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ABSTRACT

In recent years, there has been an increasing interest in alternative fuel vehicles (AFVs), such as electric vehicles (EVs), fuel cell vehicles (FCVs) and compressed natural gas (CNG) vehicles, as a promising option for mitigating global warming and reducing energy consumption. Most studies in this area have been conducted on only a few types of powertrains, e.g. EVs and gasoline vehicles; to fill this gap, this study will cover FCVs, CNGs, hybrid electric vehicles, diesel hybrid electric vehicles and liquefied petroleum gas (LPG) vehicles. This research is novel because it includes energy security aspects, uses scenario analysis and investigates FCVs. This study aims to predict an optimal AFV portfolio based on different scenarios to sustain energy security in light of gas and petroleum restrictions until 2030. To do this, we will present four scenarios that consider improvements in technology, energy security requirements, decreasing petroleum prices and government subsidies. The Polish market is considered as a case for demonstrating the optimal model. The results indicate that it is crucial to introduce all types of powertrains to achieve both economic and energy security objectives. The projected diffusion of FCVs will be more pronounced than that in previous studies, owing to the expected rapid decline in the cost of both infrastructure and purchase price of cars. Furthermore, the projected deployment of AFVs in transportation systems in this study will mostly occur in the form of lorries (trucks) and passenger vehicles. Because CNG vehicles are expected to achieve a high degree of diffusion in the transportation system, the government should seek a reliable CNG supply. Overall, this research will help automakers and policymakers recognise investment possibilities.

1. Introduction

The total global energy demand has almost doubled since 1980 and studies have estimated that approximately 20% of the global energy is consumed by the transportation sector (International Energy Agency (IEA), 2015). It has been suggested that the volatility of petroleum prices and rapid technological developments are making alternative fuel vehicles (AFVs) an increasingly promising option for decreasing energy consumption and maintaining energy security (IEA, 2015). AFVs can be defined as vehicles operating exclusively on an alternative fuels (e.g. electricity or compressed natural gas (CNG)) or on a hybrid of alternative and traditional fuels (U.S. Energy Information Administration, 2013). The AFVs investigated in this study are fuel cell vehicles (FCVs), hybrid electric vehicles (HEVs), diesel hybrid electric vehicles (DHEVs), electric vehicles (EVs) and CNG vehicles. Liquefied petroleum gas (LPG) vehicles and diesel vehicles (DV) are not generally considered to be AFVs. It is projected that between 2012 and 2040, the total volume of road vehicles will double; however, research has consistently shown that the adoption of more efficient technologies and switching to alternative fuels will slow the increase in demand for fuel relative to past periods (IEA, 2015). Recent analysis suggests that energy consumption in the transportation sector is expected to decline from 26.7 quadrillion Btu in 2012 to 25.5 quadrillion Btu in 2040, owing to a considerable decline in energy consumption through AFV use (U.S. Energy Information Administration, 2014).

Various AFVs have been developed to reduce greenhouse gas (GHG) emissions and move transport economies away from petroleum use. In addition to technological improvements, policy proposals are crucial to the market success of AFVs (Dong et al., 2014). Customers will not find AFVs attractive without an

* Corresponding author.
E-mail addresses: kamilar@keio.jp (K. Romejko), nakano@sdm.keio.ac.jp (M. Nakano).

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affordable price, easy access to spare parts and repair services and readily available fuel. Equally important, automakers, governments and energy producers will not invest in AFV infrastructure and technology without the anticipation of a sizeable market (Struben and Sterman, 2008). According to Christensen (2011), manufacturers have developed many AFV prototypes but have produced only a few on a large scale. Orsato and Wells (2007) stated that large-scale production reaching 250,000 units per vehicle model is necessary to reduce the manufacturing cost and provide affordable products. Companies cannot invest in every technology and must, therefore, develop products most promising for the spread of AFVs.

Numerous studies have investigated AFVs and their future portfolios (Graham-rowe et al., 2012; Nakano and Chua, 2011; Nanaki and Koroneos, 2013; Yabe et al., 2015; Yagcitekin et al., 2014). However, they only examined EVs or HEVs and did not consider other AFV types. In another work, the Electric Power Research Institute (2007) evaluated the impact of adding petrol (gasoline) hybrids and petrol plug-in hybrids to vehicle fleet until 2030. However, they examined neither FCVs nor electric vehicles (EVs). Most studies disregard FCVs or minimise their impact owing to outdated data. Toyota has launched an FCV into commercial production and Honda has introduced their own hydrogen FCV into the market ('Toyota, Honda get ready to launch their FCVs', 2014), and it is of utmost importance to these and other companies to accurately forecast the implementation of FCV powertrains using new data. Sandy (2009) analysed and compared the societal benefits of deploying AFVs; the most realistic of the study's scenarios (a hydrogen FCV scenario) concluded that a value of approximately \$330 billion per year could be saved in terms reductions in GHG emissions, petroleum consumption and urban air pollution. The cumulative social cost of delaying the introduction of hydrogen vehicles from 2015 to 2025 would rise by \$16 billion in 2025 (Sandy, 2009). However, the benefits of hydrogen can be accomplished only if it is produced using renewable energy. Sharma and Krishna (2015) determined that solar energy is apparently the only source of renewable energy suitable to producing enough hydrogen to accommodate a hydrogen economy. Krishnan et al. (2015) focused on assessing hydrogen as an alternative fuel in a national portfolio. They concluded that sufficient improvements in FCV investment could allow such vehicles to outperform petrol and plug-in hybrid electric vehicles (PHEVs), providing a sustainable economic option under a high renewable-power-generation portfolio, although only light duty vehicles (LDVs) were examined. In line with the above concerns, significant literature has been published on obtaining optimal portfolios using optimisation techniques; however, not all types of AFVs have been investigated and most studies have disregarded FCVs. This study seeks to remedy these gaps in the research by analysing FCVs and other types of powertrains.

Gifford and Brown (2012) assessed four types of economy using well-to-wheel analysis of automotive transportation scenarios (i.e. operation cost, primary energy consumption, GHG emissions and water usage). They found that CNG vehicles scored the highest in all four metrics in two of their scenarios. Nevertheless, their research did not include infrastructure cost. Wu and Aliprantis (2013) examined models for both transportation and national energy planning, although they did not research FCVs and their influence. Onat et al. (2015a,b) recently presented an interesting study that tackles not only environmental but also economic and social issues of sustainability in promoting AFVs. The study used a novel approach integrating compromise programming and a life cycle sustainability assessment (LCSA) framework. The conclusion from the baseline scenario was that internal combustion vehicles (ICVs) are dominant only in terms of social and economic aspects, while HEVs are preferred when environmental aspects are considered (Onat et al., 2015b). One of the major weaknesses of the study was that it disregarded FCVs, and therefore, no attempt to quantify energy security was made. Onat et al. (2015a) conducted one of the most comprehensive literature reviews on the environmental impacts of AFVs. The research evaluated and compared around 40 previous LCA studies in detail. According to the research, HEVs are the dominant vehicle type studied, and the majority of the articles make only a comparison between ICVs and AFVs. Moreover, LCA carried out by Onat et al. (2015a) examined 50 states, considered regional driving patterns and marginal and state average electricity generation mix while incorporating GHG emissions and energy consumption. Axsen and Kurani (2013); Kelly et al. (2012); Kintner-Meyer (2007); Samaras and Meisterling (2008) used LCA as a research method; however, their focus was on PHEVs and neither EVs nor FCVs were considered. In reviewing the above literature, it was found that although several attempts have been made to investigate AFVs and their implementation, most studies did not do so systematically. To address the gaps in the previous literature, this study investigates four case scenarios: Business As Usual (BAU), Energy Security, Low Petroleum Price and Subsidy.

Considerable literature has been published on the environmental or economic impacts of AFVs (Faria et al., 2013; Hawkins and Gausen, 2012; Hermann et al., 2007; Marshall et al., 2013; Nanaki and Koroneos, 2013, 2012). However, the energy security aspects of such vehicles should also be investigated. The uncertainty of future demand and supply of petroleum and gas poses a threat to energy security (IEA, 2012). To address this, the European Union (EU) has created a framework by which nations and automakers may decrease energy consumption and GHG emissions by 2020. These regulations will affect vehicle portfolios in the forthcoming years and innovations will be crucial to meeting the challenges set by the EU (Köhler et al., 2013). The conflict between Ukraine and Russia has also sparked interest in the topic of energy security in the EU as imports of resources to the EU have been interrupted in the past by political circumstances in Eastern Europe (Umbach, 2010). Hedenus et al. (2010) determined that the cost of petroleum disruption may be €29.5–31.6bn in the EU-25 countries. Wu and Aliprantis (2013) focused on LDV models used for national energy and transportation planning in the US; their results indicated that if aggressive electrification of LDVs were introduced along with investment in renewable energy, annual petrol consumption could be decreased by 66%. A comprehensive analysis of AFVs should include social, environmental and economic indicators (Litman, 2008). The European Commission (EC) listed employment, contribution to GDP, injuries and external costs of the transportation as indicators for evaluating the social and economic sustainability outlook of the transportation system (Dobranskyte-Niskota et al., 2007). A multi-criteria analysis of AFVs should be thoroughly examined to propose a holistic approach (Onat et al., 2014). Moreover, according to Litman and Burwell (2006), the socio-economic aftermaths of transportation should be investigated because quality of life is at stake. There have been only a few attempts to investigate those three dimensions. An extensive study conducted by Onat et al. (2014) considered both socio-economic and environmental impacts of AFVs and proposed 19 macro-level sustainability indicators for a scenario analysis. Another study by Onat et al. (2016) integrated the LCSA model and system dynamics to create a detailed sustainability impact assessment of AFVs. Although extensive research has been conducted on the environmental and economic aspects of AFVs, only few studies have prioritised energy security issues. To overcome this gap, we developed a model that considers resource restrictions.

Motivated by the findings from the above literature and conventional studies and by the lack of studies on the security aspects of introducing AFVs, this study examines opportunities for the