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The potential of alternative fuel vehicles: A cost-benefit analysis

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ABSTRACT

This study investigates the economic validity of the diffusion of fuel cell vehicles (FCVs) and all-electric vehicles (EVs), employing a cost-benefit analysis from the social point of view. This research assumes the amount of NOx and tank-to-wheel CO_2 emissions and gasoline use reduction as the benefits and the purchase costs, infrastructure expenses, and maintenance costs of alternative vehicles as the costs of switching internal combustion engine (ICE) vehicles to alternative energy vehicles. In addition, this study conducts a sensitivity analysis considering cost reductions in FCV and EV production and increasing costs for CO_2 abatement as well as increasing gasoline prices. In summary, the results show that the diffusion of FCVs is not economically beneficial until 2110, even if the FCV purchase cost decreases to that of an ICE vehicle. EV diffusion might be beneficial by 2060 depending on increases in gasoline prices and CO_2 abatement costs.

1. Introduction

Climate change is one of the most serious challenges of the 21st century. To avoid dangerous climate change, a variety of greenhouse gas (GHG) mitigation actions must be taken in all sectors of the global energy system. The International Energy Agency (IEA) indicated that the road transport sector accounted for approximately 17% of energy-related CO_2 emissions in 2007 and is likely to have a higher share in the future unless strong action is taken (IEA, 2009). Furthermore, if a 50% decrease in 2005 energy-related CO_2 emissions is to be achieved by 2050, the transport sector will be required to make a significant contribution. However, we should acknowledge that transport's large economic role and its significant influence on daily life will make the required rapid changes more difficult to achieve (IEA, 2000, 2008).

It is therefore critically important to develop a long-term, cost-effective strategy for reducing CO_2 emissions from the transport sector. In the past, the Japanese government implemented a number of environmental policies to move from gasoline-fueled to more efficient vehicles, such as hybrid and plug-in hybrid vehicles. As a result, the number of these alternative, efficient vehicles is increasing.

In addition, the Japanese government currently claims that 2 million all-electric vehicles (EVs) and 5 million hydrogen fuel cell vehicles (FCVs) will be on the road in Japan before 2020 (METI, 2001, Ministry of the Environment, 2009). These two types of alternative vehicles do not have tailpipe greenhouse gas emissions[1]; therefore, EVs and FCVs, alternatives to conventional vehicles based on the internal combustion engine (ICE), have the potential to greatly reduce the emissions generated by the transport sector.[2] In addition, the Japanese government has been offering subsidies to purchasers of EVs for years to boost the sales of EVs, and a number of local governments are offering additional subsidies that could reduce the purchase price of EVs (see also Ito, Takeuchi, & Managi, 2013; Kagawa et al., 2013). The main objectives of these policies are to provide incentives to early adopters and to speed the implementation of pilot programs for verifying EV and FCV technology developments.

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[1] EV vehicles are accounted for in Corporate Average Fleet Emissions in Europe. So including extra EV's in the fleet allows for more emissions by normal vehicles (Massiani & Radeke, 2013).

[2] Clearly, for comparing CO_2 emissions from each type of vehicle, well-to-wheel (WTW) analysis should be used. This analysis is combined with well-to-tank (WTT) life cycle analysis and tank-to-wheel (TTW) analysis. The WTT of a petroleum-based fuel pathway includes all steps from crude oil recovery to final finished fuel. TTW analysis includes the actual combustion of fuel in a motor vehicle for motive power.

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However, no previous study has determined when these new technologies will become economically and technologically beneficial for society by considering future energy prices, carbon prices and technological progress. The targets for the numbers of EVs and FCVs were not provided by previous studies because of their characteristics, such as short mileage per battery charge, high production costs and high purchase prices. Although car sharing services and rent-a-car businesses were introduced to resolve these issues, the targeted user's lifestyle and transport patterns were not matched with those services.[3] Thus, this study analyze whether the large-scale use of FCVs and EVs in Japan is justified from a socially economic perspective employing cost-benefit analysis, and, if so, under what conditions.

This paper first present an overview of earlier studies regarding EVs and FCVs diffusions. The following section outlines the structure of the cost-benefit and sensitivity analyses and the key assumptions in our scenarios.[4] The results of the scenarios are discussed in Section 4. Lastly, we conclude this study in Section 5.

2. Previous contributions

There is large body of literature calculating social net benefits costs (Funk & Rabl, 1999; Hahn, 1995; Kazimi, 1997a, 1997b; Lave & MacLean, 2002; Managi, 2012; Massiani & Radeke, 2013; Somanathan et al., 2014). For example, Hahn (1995) discussed the cost-effectiveness of several measures to improve environmental quality in the transport sector. This results show that improved fuel qualities and tighter air pollution standards are more cost-efficient than an introduction of battery-driven electric cars. Kazimi (1997a, 1997b) estimated the environmental benefits of introducing EVs in U.S. by using a micro-simulation model and his results show that large price reduction of alternative-fuel vehicles would not be socially beneficial. Massiani and Radeke (2013) also assess the EV policies considering the various technological, behavioral and economical mechanisms that govern the possible diffusion of EV in Germany by using a simulation tool. This study conclude that most of EV supporting policies have a negative outcome.

Although most of them find negative social benefits, Paolo (2007) noted that much more analysis examining the comprehensive components that affect the diffusion of alternative vehicles is needed. Therefore this study conducts a sensitivity analysis considering three components related to the benefit and cost for FCV and EV diffusion. First component is cost reduction in FCV and EV production. Second component is increasing CO_2 abatement costs. Last component is increasing gasoline prices.

Regarding the infrastructure setting, this paper use the data obtained from national reports on the two alternative vehicle types and interviews with car manufactures in Japan (New Energy and Industrial Technology Development Organization; NEDO, 2007). As well as the earlier studies, this studies determine the hydrogen or electric demand after assuming the number of FCVs or EVs on the road, the distance traveled and the vehicles' fuel efficiency (Jonathan, David, Thomas, & Stephen, 2011; McKinsey, 2010). By examining alternative vehicle diffusion, this study contributes to environmental research, development and the definition of adequate transport policies.

[3] Benefits from car sharing are based partly on the conversion of auto ownership from fixed to variable costs. Because drivers pay for shared cars by the hour or day, the economic efficiency of auto use can be improved by reducing the costs of maintenance, parking for drivers. Thus, EV sharing programs could contribute to reducing users' costs.

[4] The data used in this paper are represented in the Appendix.

3. Method

3.1. Cost-benefit analysis

This paper employs a Cost-Benefit Analysis (CBA) to evaluate the validity of FCV and EV diffusion from the social point of view. CBA is useful for determining the benefits of a project from an economic standpoint. In our study, the differences between net present value between benefit and cost is used as a welfare measures. In addition, this study conducts a sensitivity analysis considering cost reduction in FCV and EV production and increasing CO_2 abatement costs and gasoline prices.

3.1.1. Benefits

The reductions in NOx and CO_2 emissions and reduced gasoline use are considered as benefits that result from replacing ICE vehicles with alternative vehicles. For comparing CO_2 emissions from each type of vehicle, well-to-wheel (WTW) analysis should be used.[5] However, WTW analysis requires the total amount of CO_2 emissions in each step of the fuel and electricity production pathways. In our analysis, considering all the necessary information appears difficult owing to data unavailability. Thus, our research employs tank-to-wheel CO_2 emissions in order to simplify our scenarios.

The benefits of replacing an ICE vehicle with an alternative vehicle m (i.e., an FCV or EV) in year t is calculated as follows:

$$B_{t,m} = \sum_{p} ER_{t,p,m} \times price_{t,p} \tag{1}$$

ER indicates the amount of reduction in CO_2 and NOx emissions and in gasoline use. In the case of CO_2 and NOx, *price* represents the marginal abatement cost. In the case of gasoline, *price* indicates the price of gasoline per liter. Therefore, the benefit $_{Bt,m}$ is represented as the sum of each $_{ER}$ multiplied by the reducing cost for each material $_p$ (i.e., CO_2, NOx and gasoline).

The amount of reduction of each pollutant p and each type of vehicle m in year $_t$ is determined in Eq. (2):

$$ER_{t,p,m} = AV_{t,m} \times (E_{p,ice} - E_{p,m}) \times TD \tag{2}$$

The number of alternative vehicles (AV) indicates the number of ICE vehicles replaced by alternative vehicles from 2011 until t, i.e., the number of alternative vehicles used in year t. $E_{p,ice}$ and $E_{p,m}$ represent the emission per kilometer for pollutant p, for ICE vehicle *ice* and alternative vehicle m, respectively. TD represents the annual distance traveled per year.

Therefore, the total benefit (TB) is calculated by the sum of these components, i.e., reduced CO_2 and NOx emissions and gasoline use. The discounted present value of the benefit is then calculated and evaluated at 2011 prices. TB of type m alternative vehicle is defined as follows:

$$TB_m = \sum_{t=2011}^{T} \exp\{-i \times (t - 2011)\} \times B_{t,m} \tag{3}$$

In Eq. (3), T shows the target year for the diffusion of 5 million alternative vehicles, and i indicates a discount rate of 4%. The reason that 5 million is the diffusion target is explained in key assumption section.

[5] This analysis is combined with well-to-tank (WTT) life cycle analysis and tank-to-wheel (TTW) analysis. The WTT of a petroleum-based fuel pathway includes all steps from crude oil recovery to final finished fuel. TTW analysis includes the actual combustion of fuel in a motor vehicle for motive power.