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A cost-benefit analysis of the carbon footprint with hydrogen scooters and electric scooters

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ABSTRACT

This study analyzes the carbon footprint of an internal combustion engine scooter (ICE) and there are four types of electric scooters studied, namely: a hydrogen fueled scooter with on-board methanol steam reforming (on-board SMR), hydrogen scooter with methane steam reforming (SMR), plug-in electric scooter (PEV), and hybrid scooter. This paper also uses a sensitivity analysis to examine how the variations in fuel prices influence the cost-benefit of using a hydrogen scooter. The research results are as follows: (1) SMR and on-board SMR have the smallest carbon (0.0115 kg $CO_{2,e}$& 0.0117 kg $CO_{2,e}$), PEV (0.0189 kg $CO_{2,e}$), hybrid scooter (0.0614 kg $CO_{2,e}$) and ICE (0.1378 kg $CO_{2,e}$); the percentage of carbon emissions relative to ICE by each scooter are, in ascending order, 8%, 8%, 14% and 45%; (2) according to the ISO14067 standard, capital goods (fixed costs) cannot be accounted into total life cycle costs, and total life cycle costs excluding fixed costs are in descending order, SMR ($6632), ICE ($4233), on-board SMR ($3643), hybrid scooter ($3368) and PEV ($2824); (3) the variation of fuel price is the key factor of using hydrogen scooters.

Introduction

The Intergovernmental Panel on Climate Change [7] Fifth Assessment Report (AR5) stated that temperature of the earth rose about 0.85 °C from 1880 to 2012, due to the release of greenhouse gases (GHG), and the resulting climate change is leading to the destruction of many ecological systems. The International Energy Agency [8] noted that fossil fuel combustion is responsible for the majority of greenhouse gas emissions. According to the IEA [8]; in 2012 the CO_2 emissions by sector were, in a descending order, mainly from the electricity and heat production sector (42%), followed by the transport sector (23%), industry sector (20%), other sectors (10%) and other energy industry own use sector (5%), with road transport accounting the largest portion of CO_2 emissions in the transportation sector. The IEA [8] also stated that road transport was responsible for 64% of emissions in the transport sector in 1990, and that this had risen to 75% by 2012.

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The CO_2 emissions from the transportation sector in Taiwan totaled 34,472 thousand tonnes in 2013, accounting for 13.77% of total emissions. This is 1.75 times higher than the emissions in 1990 (19,646 thousand tonnes), and this sector is thus the second emitter of CO_2 emissions in Taiwan. It is important for Taiwan to reduce this figure. The use of motor vehicles in Taiwan is different from that of many other countries. According to the Ministry of Transportation and Communications in Taiwan [10], there are 418.3 scooters/km^2 in Taiwan, compared to the numbers in Singapore (205.7 scooters/km^2), Hong Kong (51.6 scooters/km^2), Japan (32.9 scooters/km^2), Germany (11.4 scooters/km^2) and the U.S.A (5.1 scooters/km^2). Taiwan thus has a very high density of scooter usage.

According to TEDS8.1, the engines of scooters release PM_{10},SO_x, NMHC and Pb, which account for 20%, 14%, 47% and 21% of emissions from the transportation sector respectively. It is thus important to seek alternative fuels with scooters to reduce GHG emissions and improve air quality. Ogden et al. [12] researched the life cycle of several alternative fuel vehicles for carbon emissions, including those using hydrogen/gas hybrid, gas/electric hybrid, compressed natural gas and hydrogen fuel cells, with the last having the lowest externalities. Colella et al. [2] examined the environmental benefits of hybrid electric fossil fuel vehicles and hydrogen fuel cell vehicles, and found that the latter had the best ability to reduce GHG emissions. Wang et al. [13] used a life cycle approach to analyze the potential air quality impacts of hydrogen and gasoline use in light duty vehicles. The life cycle of hydrogen vehicles includes hydrogen production, compression, liquefaction and transportation. The results showed that CO emissions from using fossil fuel may be 273 times higher than when using hydrogen fuel, and that NO_X, VOC and PM emissions are 3.5, 88 and 8 times higher respectively. It is thus clear that hydrogen vehicles could greatly reduce GHG emissions. Hwang [6] reviewed the current development of fuel cell scooters in Taiwan and provided some suggestions based on a SWOT analysis, concluding that Taiwan has a niche that would enable to develop hydrogen scooters using advanced hydrogen fuel cell technology. Das and Dutta [3] studied on the use of a fleet of hydrogen scooters in New Delhi, India and Zubelzu and Álvarez [14] reported that carbon footprint assessments can be used to effectively control carbon emissions.

Greene et al. [5] examined the factors affecting the future market share of hydrogen-powered vehicles, and found that scooter costs are the most important in determining future market share. However, in the long term, because of rising awareness of environmental protection, the influence of scooter cost may fall. Noel and McCormack [11] conducted a sensitivity analysis to determine how vehicle and diesel prices influence the costs and benefits associated with the use of electric vehicles, and found that both factors affect the intention of buying such vehicles.

Based on the above, the purposes of this study are as follows: (1) analyzing on-board SMR, SMR, PEV, hybrid scooters and ICE to find which has the least carbon footprint and is the most beneficial to the environment. The carbon footprint analysis is based on the ISO/TS14067 standard; (2) analyzing the incremental costs of four types of alternative scooters compared to ICE scooters, which are most commonly used; (3) analyzing the fluctuations in the price of gasoline to examine the sensitivity of incremental costs with regard to hydrogen scooters and ICE scooters.

The framework of this study is as follows. Chapter one presents the research background, motivation and purposes. Chapter two then introduces the research methods, as well as the CFP assessment and defines the boundaries of the related life cycle. Chapter three presents the empirical analysis, showing the system of hydrogen scooters and giving the research hypothesis, in addition to the research results. Chapter four presents the conclusions and offers suggestions based on the research results.

Research methods

Assessment of carbon footprint

A carbon footprint is defined as the total greenhouse gas emissions from direct or indirect processes caused by an activity or a product. The life cycles of physical products are divided into five phases, which are named as follows: raw materials phase, production phase, distribution phase, consuming phase and waste disposal phase. However, the life cycle of intangible services are focused on the emissions of the consumer use phase, or so called service phase. This paper discusses the carbon footprint of scooter services to assess the total carbon emissions in the scooter usage stage.

This study is based on the ISO/TS14067: 2013 Greenhouse gases—Carbon footprint of products—Requirements and guidelines for quantification and communication for the assessment of the life cycle GHG of goods and services. Life Cycle Assessment (LCA) includes the phase in the production and use of a product or service, including the acquisition of raw materials and natural resources, manufacturing, transportation, customer use, disposal, and recycling or recovery. The emission factors in this study are retrieved from SimaProv8.

Setting boundaries and maps of a manufacturing process

When studying carbon footprints it is important to set appropriate boundaries. The boundary of this study is set by the operation's phase, which in this work is termed the service carbon footprint. The phases involved in the production of scooters are thus ignored. Fig. 1 is the LCA framework regarding scooter services, based on the work of McKenzie and Durango-Cohen [9]. The service phase is examined in this paper, and this includes three stages, namely: supply replacement, operations, and disposal. The white boxes in Fig. 1 thus indicate factors that are considered in this work, while the grey boxes are those that are excluded, and these are related to the scooter manufacture, scooter disposal and the processes for obtaining the raw materials.

The service flow figures for five scooters are shown in Figs. 3–7. IC engine scooters (ICE) and plug-in electric scooters (PEV) have well-developed production processes in the scooter market, while hydrogen fueled scooters with on-board methanol steam reforming (on-board SMR) and hydrogen scooters with methane steam reforming (SMR) remain in the experimental stage, having completed road tests but not on