Low-carbon Energy in Scooter Applications

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Abstract

This paper refers to *ISO/TS 14067:2013* to evaluate the carbon footprints of an internal combustion engine (ICE) scooter and three scooters using different forms of energy, liquefied natural gas (LNG), hydrogen and electricity, examining the fuel usage with a life cycle assessment. The results reveal that the following: (1) The ICE scooter has the highest carbon footprint over its life cycle, at 0.1418 kgCO_2,e /km. In contrast, the hydrogen scooter has the lowest carbon footprint at 0.0169 kgCO_2,e/km. (2) The total life cycle costs, in descending order, are those for the hydrogen scooter ($19,477.71), electric scooter ($6,991.64), ICE scooter ($6,811.60) and LNG scooter ($4,978.61). (3) The LNG scooter has the best cost-benefit value. While in terms of environmental benefits, the hydrogen scooter has the most potential for development, although it does not have economic benefits. Therefore, in view of the environmental benefits, this paper suggests that hydrogen-based energy should be used more widely in public transportation.

Keywords：Liquid nature gas、Hydrogen、Carbon footprint、Scooter、Life cycle assessment

Chapter 1 Introduction

IEA applied the energy consumption data from the period of 2002 to 2013 in 2015, pointing out that the main source of global greenhouse gases (GHG) comes from burning large quantities of fossil fuels. From 2002 to 2013, CO_2 emissions from burning oil has been reduced by 6% to 33% currently, however, contrastingly from coal (46%) and natural gas (20%), had continued to increase. In addition, the proportion of global CO_2 emissions in 2013 was 42% in the electricity and heat production sector, 23% in the transport sector. According to the IEA in 2015, from 1990 to 2003 the CO_2 emissions in road transport have increased by about 68%overall. By 2013, road transport CO_2 emissions had already accouted for three quarters of the transport sector; much higher than the total emission of sea transport, air transport and rail transport all combined. Thus, how to reduce GHG emissions from road transport in the transport sector is an important issue.

Arteconi et al. (2010) took heavy-duty vehicles as a main research objective in the European market (EU-15), and he applied the life cycle approach to measure the use of LNG energy. The result showed that LNG-TER scenario (indicating the life cycle of LNG was first transferred to Europe by the methane carrier ship, and transformed into liquefied type in the regasification terminal) enables at least a 14% reduction in GHG emissions in comparison with diesel. Shang and Pollet (2010) also evaluated the life cycle emission of a hydrogen fuel cell hybrid scooter (HFCHS) in the University of Birmingham campus. The results found that the energy consumed by the HFCHS was 0.11 kWh/km HFCHS, with an associated £0.01/km running cost and a well-to-wheel CO_2 of 9.37 gCO_2/km, which indicates that HFCHS gave better energy efficiencies than the lead-acid battery electric scooter (GoPed). Huang (2012) compared three different energy-based scooters, including NG-based hydrogen fuel cell scooter, battery electric scooter and ICE scooter, in order to find out their defferences in energy consumption and emission reduction efficiency during serving period. The result showed that, if replacing diesel energy by hydrogen fuel cell is applied, the scooter could reduce about 58% GHG emission and improve 35% energy conservation efficiency.

In low-carbon energy, hydrogen is one worth mentioningbecause thhe most popular way of producing hydrogen is through Steam Reforming (Renewable Energy World, 2016). And hydrogen energy needs high power resistance, which can produce about 142 million joules per kilogram of energy, and is three times higher as compared to gasoline, 3.5 times higher than natural gas. Moreover, when it burns in internal combustion engine (ICE), it only produces high density of energy and water without causing pollution which makes it a clean energy source.

According to the CO_2 emissions of fuel combustion statistics published by the Ministry of Economic Affairs in 2015, which pointed out that the total CO_2 emissions in 2014 (excluding electricity consumption emissions) increased by1.93 million tonnes compared with the emission in 2013. Moreover, annual CO_2 emission growth rate from 1995 to 2014 was 3.52%, as detailed in table 1.1, showing the increasing trend in each sector. In which, the transport sector is third-largest source of CO_2 emissions in Taiwan and comparing with the emissions of2013, the emissions in 2014 grew by 1.34%. Furthermore, according to the National Greenhouse Gas Inventories Report (2015) in Taiwan, by 2013 the share of CO_2 emissions from transport, in descending order, are road transport (97.72%), maritime transport (1.36%), air transport (0.69 %), and rail transport (0.24%). Therefore, it is necessary to reduce the CO_2 emissions from the road transport sector to avoid environmental degradation.

Table 1.1 Taiwan CO_2 emissions from fuel combustion by sector in 2013 and 2014

(Unit：ten thousand tons)

year \ sector		Energy	Industry	Transport	Agriculture	Service	Residential
2013	amount	16,023.88	4,456.20	3,447.22	100.88	417.67	464.92
	%	64.33%	17.89%	13.84%	0.40%	1.68%	1.87%
2014	amount	16,568.71	4,031.68	3,493.38	107.43	441.10	461.59
	%	66.00%	16.06%	13.92%	0.43%	1.76%	1.84%
Growth Situation	%	3.40%	-9.53%	1.34%	6.49%	5.61%	-0.71%

Data Resource：Bureau of Energy, Ministry of Economic Affair (2015)

In general, there are two ways to solve the emission problems from the transport sector, one is to control the number of vehicles on the road, however, in Taiwan people strongly rely on private transport such as scooters,cars,e.t.c. thus, without any specific policy, the number to control the amount of vehicles is very hard to implement. The other one is the use of alternative energy in transportation, in other words, using low-carbon energy instead of the natural diesel and other high-carbon energy to reduce the GHG emissions in the transport sector. With theview of this, this paper will apply ISO/TS 14067: 2013 with carbon footprint (CF) model to evaluate the carbon footprint of internal combustion engine (ICE) scooter and other three alternative energy-based scooter, including liquefied natural gas (LNG) scooter, hydrogen scooter and electric scooter.

Based on the above reasons, the objectives of this paper are as follows:

1. Analyze the life cycle carbon footprint of ICE scooter, LNG scooter, hydrogen scooter and electric scooter, and compare the environmental benefits of them and their emission hot-spots.

2. Evaluate the life cycle cost and applying cost-benefit analysis to analyze the cost-benefit of the four different kinds of scooters.

3. Provide the improvement direction for low-carbon energy in scooter application and green transport strategy.

Chapter 2 Research Methods

2.1 Assessment of Carbon footprint

This section is constructed based on the carbon footprint process as defined by ISO/TS 14067. And first, we set up a service flow chart (Fig. 2.1, Fig. 2.2, Fig. 2.3, Fig. 2.4) to clarify the service flow of carbon footprint for scooters' life cycle. Then according to the life cycle perspective of ISO/TS 14067, this study divides the scooter service phase into raw material extraction phase, manufacturing phase, product service phase and waste disposals phase. However, based on the vehicle boundary principle, the raw material extraction and manufacture phase, simply includes scooters that needed fuel and their maintenance excludes the emission caused during the scooter's manufacturing. In which, the carbon emission of fuel and maintenance can date back to the primary stage of energy source, fuel production, distribution and waste management (including recycle and landfill). And based on the relative approach and functional unit principle, which provided the the measurement standard for carbon footprint calculation for the four scooters. The functional unit of this study is $kgCO_2$,e/km (vehicle kilometer traveled) indicating the emission of scooters per kilometer. The maps of these four scooters are as follows.

1、ICE scooter

The life cycle of the service flow figures of internal combustion engine scooter (ICE scooter) is shown in Fig. 2.1, which can be divided into three phases, namely: raw material extraction and manufacturing flow, service flow and waste disposals flow.

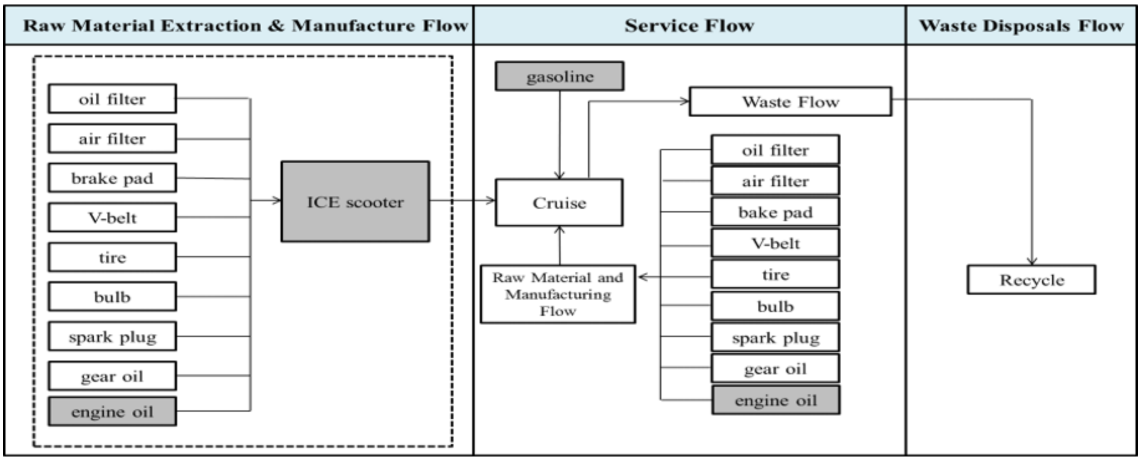

Fig. 2.1 ICE scooter life cycle.

2、LNG scooter

Because the current LNG energy in transport applicationsmainly focuses in large vehicles and in shipping transportation rather than in scooters application. Thus, this study surposedly that nowadays there have been enough technology to produce LNG scooters. Furthermore, except the differences in power generation, the use of LNG scooter is similar with ICE scooters. The life cycle of the service flow figures is shown in Fig. 2.2.

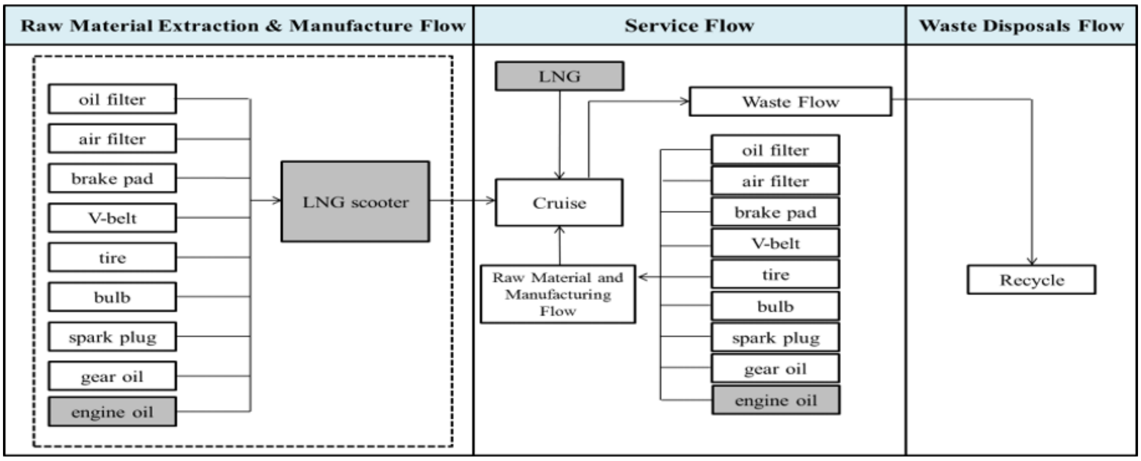

Fig. 2.2 LNG scooter life cycle.

3、hydrogen scooter

Chang et al. (2016) current hydrogen production forhydrogen scooter was mainly extracted by methanol steam reformer and steam methane reforming (SMR). In which, comparing the carbon footprint in passenger-kilometers of both scooters, the SMR scooter (0.0115 $kgCO_2$,e) yielded more emission reduction than methanol steam reformer scooter (0.0117 $kgCO_2$,e). In addition, in Taiwan about 95% of hydrogen is produced in this way. Therefore, in this study the hydrogen power of hydrogen scooter would apply SMR. The service flow figures is shown in Fig. 2.3.

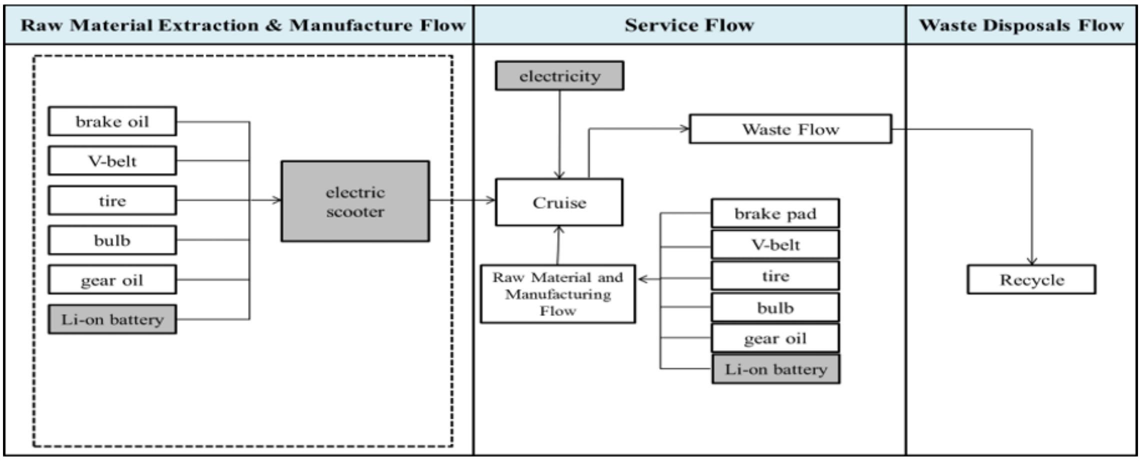

Fig. 2.3 hydrogen scooter life cycle.

4、electronic scooter

The life cycle of the service flow chart of electronic scooter is shown in Fig. 2.4.

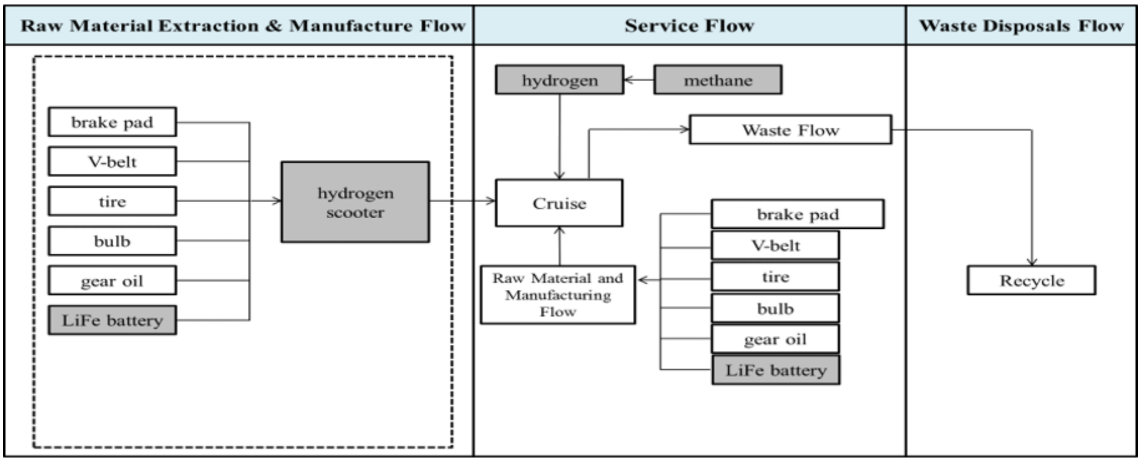

Fig. 2.4 electronic scooter life cycle.

2.2 Variables and model

2.2.1 Variables

The purpose of this study is applying carbon emission and carbon footprint model to calculate the unit energy emission of four energy-based scooters. The required variables are including actual activity data and emission factors for carbon emission model and carbon footprint model, as shown in Table 2.1.

Table 2.1 variables used in the carbon footprint model

Variables	Definitions
A_ι	activity intensity of ι items, ι=1~14 ι=1, gasoline, ι=2, engine oil, ι=3, LNG, ι=4, methane, ι=5, electricity, ι=6, gear oil, ι=7, air filter, ι=8, V-blet, ι=9, tire, ι=10, bulb, t=11, LiFe battery, ι=12, Li-on battery, ι=13, LNG storage device, ι=14, hydrogen storage device
E j	emission factor of j items, j =1~16 j=1, gasoline, j=2, engine oil, j=3, LNG, j=4, methane, j=5, electricity, j=6, gear oil, j=7, air filter, j=8, V-blet, j=9, tire, j=10, bulb, j=11, gasoline combustion, j=12, LNG combustion, j=13, LiFe battery, j=14, Li-on battery, j=15, LNG storage device , j=16, LNG storage device
TE_γ/ CFP_γ	carbon emission/footprint of γ scooter(γ=1~4) γ=1, ICE scooter, γ=2, LNG scooter, γ=3, hydrogen scooter, γ=4, electric scooter
other variables	M, mileage (kilometer), FE_1, fuel efficiency of ICE scooter (km/l), FE_2, fuel efficiency of LNG scooter(km/m^3), P1, scooter’s first life cycle phase: maintenance item phase, P2-1, scooter’s second life cycle phase: extraction and manufacturing-fuel phase, P2-2, scooter’s third life cycle phase: scooter serving-fuel phase

2.2.2 Life cycle carbon footprint calculation model

1、Models of carbon emissions

According to the emission asessement provided by the Environmental Protection Administration of the Executive Yuan, the carbon footprint models used in this study is shown in Eq. (1).

$$\text{Carbon Emissions } (CO_2,e) = \text{Activity Intensity} \times \text{Emission Factor} \times \text{GWP} \tag{1}$$

The total emission (TE) model of scooter service phase was based on the Eq. (1), and we further added activity intensity/variation (ι) and emission factor (j) data of each scooter's (γ) fuel and consumptions items, which is shown in Eq.(2). However, Eq. (2) did not multiply the GWP value, that is because the emission factor used in this paper had changed all the GHG emission into the CO_2,e.

$$TE_\gamma=\Sigma_{\iota j}\, A_\iota \times E_j \tag{2}$$

$TE\gamma$：represents the life cycle carbon emission of γ scooter

A_ι：represents the activity intensity of ι item (ι=1~15)

E_j：represents the emission factor of j item(j =1~17)

The following were the the carbon emission models of ICE scooter, LNG sooter, hydrogen scooter and electric scooter.

(1) when γ=1，represneting the carbon emission of ICE scooter(TE_1, Unit：kgCO_2,e)

$$TE_\gamma=\Sigma_{\iota j}\, A_\iota \times E_j，(\iota,j)=(1,1)，(1,11)，(2,2)，(6,6)，(7,7)，(8,8)，(9,9)，(10,10) \tag{3}$$

(2) when γ=2，represeneting the carbon emission of LNG scooter(TE_2, Unit：kgCO_2,e)

$$TE_\gamma=\Sigma_{\iota j}\, A_\iota \times E_j，(\iota,j)=(3,3)，(3,12)，(2,2)，(6,6)，(7,7)，(8,8)，(9,9)，(10,10)，(13,15) \tag{4}$$

(3) when γ=3，representing the carbon emission of hydrogen scooter (TE_3, Unit：kgCO_2,e)

$$TE_\gamma=\Sigma_{\iota j}\, A_\iota \times E_j，(\iota,j)=(4,4)，(6,6)，(7,7)，(8,8)，(9,9)，(10,10)，(11,13)，(14,16) \tag{5}$$

(4) when γ=4，representing the carbon emission of electric scooter (TE_4, Unit：kgCO_2, e)

$$TE_\gamma=\Sigma_{\iota j}\, A_\iota \times E_j，(\iota,j)=(5,5)，(6,6)，(7,7)，(8,8)，(9,9)，(10,10)，(11,13)，(12,14) \tag{6}$$

2、Carbon footprint models

The carbon footprint is based on the product's life cycle, which was composed of systematic GHG emission and removal amount, and using single CO_2,e to measure the impact of climate change and evaluate the functional unit of carbon emission. The functional unit in this study was vehicle kilometer traveled and the scooters' carbon footprint models are shown in Eq.(7).

$CFP_\gamma = TE_\gamma/M$ (7)

CFP_γ：carbon footprint of vehicle kilometer traveled of γ scooter. (unit：$kgCO_2$,e/pkm) (γ=1~4)

TE_γ：life cycle carbon emission of γ scooter. ($kgCO_2$,e) (γ=1~4)

M：milage (kilometer)

2.3 Cost-benefit analysis

Due to LNG and hydrogen energy in scooter application are not mutured yet,comparing the electric scooters and ICE scooters, the fixed cost of LNG scooters and hydrogen scooters are much more expensive. In addition, this study will mainly to assess the novel and low-carbon energy such as LNG and hydrogen in scooter applications, and evaluating their fuel cost in the 15 years life expectancy, which belonged to the variable cost. Thus, this study assumed in the future the manufacture of LNG scooters, hydrogen scooters and electric scooters become mature, which neglect the impact of fixed cost and compare the ICE scooters to find which energy-based scooter has the best development potential.

Desciption	Variable
The life cycle cost-benefit ration of γ scooter，γ=1~4	BC_γ
The life cycle carbon emission of γ scooter ($kgCO_2$,e)，γ=1~4	TE_γ
The net present value of life cycle total cost of γ scooter，γ=1~4	PV_γ
The life cycle fixed cost of γ scooter，γ=1~4	FC_γ
The life cycle variable cost of γ scooter，γ=1~4	VC_γ

Note：γ=1，ICE scooter；γ=2，LNG scooter；γ=3，hydrogen scooter；γ=4，eletric scooter。

The cost-benefit models are shown below：

$BC_\gamma=TE_\gamma/PV_\gamma$ (8)

BC_γ：the ration of scooter's life cycle cost-benefit

TE_γ：Life cycle carbon emission reduction ($kgCO_2$,e) of γ scooter, comaparing it with ICE scooter

PV_γ：Life cycle carbon incremental cost (USD) of γ scooter, comaparing it with ICE scooter

The cost and the benefit of the cost-benefit model are based on the three different energy-based (LNG, hydrogen and electric) scooter's life cycle carbon reduction and incremental cost comparing it with ICE scooter.

Chapter 3 Empirical Analysis

3.1 Scooter characteristics

Table 3.1 is the basic specifications and activities data of the four energy-based scooters used in this study.

Table3.1 Basic Scooter characteristics.

	ICE scooter	LNG scooter	Hydrogen scooter	Electric scooter
H*W*D	1,800×700× 1,080 mm	1,800×700× 1,080 mm	-	1,765×665× 1,075 mm
Max speed	100 km/hr	65 km/hr	65 km/hr	50 km/hr
Max power	7,500 W	3,000 W	3,000 W	2,000 W
Capacity of battery	-	-	59.2V/30Ah	48V/20Ah*2

3.2 System boundary of the life cycle carbon footprint of scooter

The assessment of hydrogen scooter in this study is based on Chang et al. (2016), of which the fuel cell is produced by Ballard Power Systems. According to the report published by Frost & Sullivan, the average life expectancy of Ballard Power Systems' fuel cell is about 40,000 hours, approximately 15 to 20 years (Frost & Sullivan, 2011). However, the fuel cell is the most expansive and important part of a hydrogen scooter, therefore, the life expectancy of the fuel cell for hydrogen scooter in this study is set up to 15 years conservatively, and then comparing with other energy-based scooters using the same life expectancy estimate(15 years) of life cycle carbon footprint.

According to a survey about the use of scooters in 2014, published by the Taiwan MOTC in 2015, on average the travelling distance of a scooter in 2014 was about 3.1 million kilometers, the length per week was 4.9 days, and the length per day was 51.8 minutes. Furthermore, on average the distance per day was 12.4 kilometers, which was 1.2 kilometers less than in 2011, and each index also decreased compared to the survey in 2011.

Therefore, based on the above report, we assumed that the life cycle of ICE scooter, LNG scooter, hydrogen scooter and electric scooter, their service life are approximately 15 years. And the decision of the functional units, we refer to the 2015 statistics report published by MOTC and used kgCO2,e/km (vehicle kilometer traveled), which indicates the emission per kilometer for scooters. We multiplyed the daily distance (12.4 km) with the number of days per year (365), so the total scooter riding distance in Taiwan is about 4,526 km per year. Finally, we considered the life expectancy of the scooters, and we multiplyed by 4,526 km for 15 years, so the total life cycle distance was 67,890 km. In the fuel efficiency phase, although these four scooters used different energy sources, they all belonged to the original heavy-duty motorcycle in the scooter's category of MOTC. And in 2014 the average distance per liter fuel consumption for ICE scooters is 22.2 km (MOTC, 2015). Furthermore, based on MOTC (2013), in Taiwan the average occupancy of scooters is about 1.34 people per scooter, thus, we assumed that the occupancy of scooters in this study is 1.0 person per scooter.

Due to the lack of LNG scooter example currently, the calculation of this study is based on the heating value of LNG and LPG energy for energy transformation. The heating value of LNG and LPG were 13,039 kJ/kg and 12,000 kJ/kg, respectively, the ratio was about 1.09, thus, we conservatively used the ratio 1, namely, the same to calculate the life cycle fuel comsuption of LNG scooter.

3.3 Carbon footprint assessment

3.3.1 Carbon emission assessment

1、The carbon footprint of ICE scooter

The total GHG emission of the ICE scooter is 9,629.86 $kgCO_2$,e (Table 3.3). In which, the emission sources is in descending order where phase P2-2,is scooter serving-fuel phase at 7,222.30 $kgCO_2$,e (75.00%), P2-1,is extraction and manufacturing-fuel phase at 2,135.18 $kgCO_2$,e (22.17%), and P1,is maintenance phase at 272.38 $kgCO_2$,e (2.83%).

2、The carbon footprint of the LNG scooter

The total carbon emission of LNG scooter is 4,556.20 $kgCO_2$,e. And the emission sources are in descending order are P2-2,which is scooter serving-fuel phase at 3,628.44 $kgCO_2$,e (79.64%), P2-1,is extraction and manufacturing-fuel phase at 557.10 $kgCO_2$,e (12.23%), and P1,is maintenance phase at 370.66 $kgCO_2$,e (8.14%), in which the orderof each of them is the same with the ICE scooter.

3、The carbon footprint of the hydrogen scooter

The carbon emission sources of hydrogen scooter in descending order are P1, maintenance phase at 643.20 $kgCO_2$,e (56.07%), P2-1, extraction and manufacturing-fuel phase at 503.98.10 $kgCO_2$,e (4.93%), and P2-2, scooter serving-fuel phase at 0 $kgCO_2$,e (0%). And the total carbon emission of the hydrogen scooter is 1,147.18 $kgCO_2$,e.

4、The carbon footprint of the electric scooter

The total carbon emission of the electric scooter is 1,217.37 $kgCO_2$,e. And the emission source in descending order of the electric scooters are P2-1, extraction and manufacturing-fuel phase of 796.58 $kgCO_2$,e (65.43%), P1, maintenance phase of 420.81 $kgCO_2$,e (34.57%), and P2-2, scooter serving-fuel phase of 0 $kgCO_2$,e (0%).

Therefore, the total life cycle emission in descending order of ICE scooter (9,629.86 $kgCO_2$,e), LNG scooter (4,556.20 $kgCO_2$,e), electric scooter (1,217 $kgCO_2$,e) and hydrogen scooter (1,147.18 $kgCO_2$,e). Furthermore, the ICE scooter has much higher emission than other energy-based scooters, which is 2.11 times, 8.39 times and 7.91 times higher than LNG scooter, hydrogen scooter and electric scooter, respectively.

In P1, maintenance phase, the electric scooter produce the most emission of 796.58 $kgCO_2$,e, and the followed by hydrogen scooter of 643.20 $kgCO_2$,e, that was because both hydrogen scooter and electric scooter required to be equipped with batteries, and batteries replacement produce high emission during scooter's yearly usage. In P2-1, extraction and manufacturing-fuel phase, the ICE scooter emited the most GHG of about 2,135.18 $kgCO_2$,e, and t followed by electric scooter with 796.58 $kgCO_2$,e due to the high emission in electricity production before serving. And in P2-2 , scooter serving-fuel phase, ICE scooter also gave the highest emission of 7,222.30 $kgCO_2$,e and followed by LNG scooter with 3,628.44 $kgCO_2$,e, while hydrogen scooter and electric scooter had no emission in this phase.

3.3.2 Carbon footprint assessemnt

The carbon footprint ($kgCO_2$,e/km) in this study is the total life cycle emission divided by toal traveling distance of 67,890 kilometers. The result of four scooters' carbon footprint are shown in Table 3.3. The ICE scooter gave the most carbon foot print of 0.1418 $kgCO_2$,e/km, and in descending order are the LNG scooters of 0.0671 $kgCO_2$,e/km of carbon footprint, electric scooter of 0.0179 $kgCO_2$,e/km and hydrogen scooter of 0.0169 $kgCO_2$,e/km. In the GHG emission reduction part, comparing with the ICE scooter, LNG scooter, electric scooter and hydrogen scooter gave 5,073.66 $kgCO_2$,e (52.69%), 8,482.68 $kgCO_2$,e (87.39%) and 8,412.47 $kgCO_2$,e (88.09%) less emission, respectively.

Table 3.3 whole life cycle carbon footprint of scooters

	ICE	LNG	hydrogen	Electric
Carbon emission ($kgCO_2$,e)	9,629.86	4,556.20	1,147.18	1,217.39
Carbon footprint ($kgCO_2$,e/**km**)	0.1418	0.0671	0.0169	0.0179

3.4 Cost assesment

1、ICE scooter

According to domestic scooters sales volume data from Jnauary to July in 2015 published by the Ministry of Transportation and Communications (MOTC), the fixed cost of ICE scooter used the average of 12 scooters for the four main scooter manufacturers in Taiwan, and the final average price was 2,307 US dollar per scooter. And the variable cost of the 15-year service life cycle of the IEC scooter was $ 4,504.60 USD, which are shown in Table 3.4 and Table 3.5.

2、LNG scooter

For LNG scooter this study referred to the report of Liberty Times Net in 2008, in which with about 500 US dollar conversion fee we could modify ICE scooter into LNG scooter. Thus, the fixed cost of LNG scooter was about $ 2,807 USD.

The calculated price of LNG energy in this study, we referred to the fuel data from 2011 to 2015, published by the Marketing Business Division of CPC Corporation, the average of 5-year price was $ 0.56 USD per square meter. Thus, according to the results, the total variable cost of LNG scooter was $ 2,171.61.

3、hydrogen scooter

In this study, the fixed cost of the hydrogen scooter is based on Chang et al. (2016), which is about $ 12,672 USD. And the hydrogen energy source of the hydrogen scooter is based on the Methanol Steam Reformer technology. In addition, in the life cycle, the hydrogen scooter needs to replace its battery with two extra LiFe batteries, thus, the variable cost should include the hydrogen energy resource and LiFe batteries. Accoding to the result, the total variable cost of the hydrogen scooter is $ 6,805.71 USD.

4、electric scooter

The way for electric scooter to charge batteries is going to battery charging station, and the technical staff would help you replace it in about 3 minutes. In which, each battery is garrentteed an endurance of about 40 km. And membership fee for charging the electric scooter is about $ 116 USD. Thus, the life cycle cost of electric scooter should include its maintenance, LiOn batteries usage fee and replacement with the extra LiFe batteries. The results show the total variable cost of the electric scooter is $ 4,595.64 USD.

5、life cycle cost of scooters

The life cycle cost of four different energy used scooter, in descending order are the hydrogen scooter at $ 19,477.71 USD, the electric scooter at $ 6,991.64 USD, the ICE scooter at $ 6,811.60 USD and the LNG scooter at $ 4,978.61 USD.

Table 3.4 whole life cycle variable cost of scooters

item	ICE	LNG	hydrogen	electric
fuel	3,242.54	909.55	4,066.67	-
engine oil	246.84	246.84	-	-
gear oil	56.78	56.78	113.56	113.56
air filter	116.62	116.62	-	-
brack pad	120.00	120.00	120.00	120.00
V-belt	280.00	280.00	280.00	280.00
spark plug	35.00	35.00	-	-
tire	366.74	366.74	366.74	366.74
bulb	40.08	40.08	40.08	40.08
LiFe battery	-	-	1,818.66	1,818.66
Lion battery	-	-	-	1,740.60
usage fee	-	-	-	116.00
total	**4,504.60**	**2,171.61**	**6,805.71**	**4,595.64**

In this, the variable cost of ICE engine scooter and the electric scooter was higher than the fixed cost. While the fixed cost of the LNG scooter and the hydrogen scooter was higher than the variable cost, as shown in Table 3.5. below

Table 3.5 whole life cycle cost of scooters

cost	ICE scooter	LNG	hydrogen	electric
fixed cost (%)	2,307 (33.87%)	2,807 (56.38%)	12,672 (65.06%)	2,396 (34.27%)
variable cost(%)	4,504.60 (66.13%)	2,171.61 (43.62%)	6,805.71 (34.94%)	4,595.64 (65.73%)
Total	**6,811.60**	**4,978.61**	**19,477.71**	**6,991.64**

note：Unit USD ($ 1 USD = $ 30 NTD)

3.5 Cost-benefit analysis

The cost-benefit analysis in this study: costs and benefit is based on the incremental cost and the total carbon reductions comparing with the ICE scooter. We could use the ratio between cost and benefit to measure the benefit of different choices. In this way, by giving extra $ 1 USD for GHG reduction for each scooter, we would discover which scooter had the most carbon reduction efficiency.

The total incremental cost, carbon emission reduction, and benefit-cost ratio of the LNG scooter, the hydrogen scooter and the electric scooter, compared with the ICE scooter are shown in Table 3.6. The BC ratio was the best when its value was negative, while if its value is positive, then the BC ratio is better when the value is a bit higher. According to the result, the BC ratio of the LNG scooter is -2.77 kgCO_2,e/USD, which is the most environmentally effective scooter, indicating that comparing with the ICE scooter, when the LNG scooter reduced about $ 1 USD, then it could also reduce about 2.77 kgCO_2,e GHG emission. And the BC ratio of the hydrogen scooter and the electric scooter are 0.67 kgCO_2,e/USD and 46.73 kg CO_2,e/USD respectively, which the value of BC ratio are both positive.

In the same logic, if we reversed the BC ratio, make the numerator an incremental cost factor and the denominator a carbon reduction factor, we could get the incremental cost by reducing 1 unit GHG emission. The concept of this ratio is similar with BC ratio, which was best when its value was negative, while if its value was positive, the BC ratio was better when the value was more higher. The ratio of the LNG scooter was -0.36 USD/kgCO_2,e, which was the most environmentally friendly effective scooter and it indicated that comparing it to the ICE scooter when the LNG scooter reduces about 1 kgCO_2,e emission, it could also save $ 0.36 USD. The following are the electric scooter emissions, at 0.02 USD/kgCO_2,e and the hydrogen scooter at 1.49 USD/kgCO_2,e, which indicated that comparing it to the ICE scooter, when the electric scooter reduces about 1 kgCO_2,e, the cost of $ 0.02 USD is needed, while for the hydrogen scooter, $ 1.49 USD was needed to reduce 1 kgCO_2,e, in which the cost is much higher than other scooters.

Thus, based on the BC ratio, the best environmentally efficient scooter was the LNG scooter, followed by the electric scooter, and the hydrogen scooter.

Table 3.6 the incremental cost, emission reduction and BC ratio

	ICE	**LNG**	**hydrogen**	**electric**
life cycle cost	6,811.60	4,978.61	19,477.71	6,991.64
incremental cost	-	-1,832.99	12,666.11	180.04
life cycle emission	9,629.86	4,556.20	1,147.18	1,217.39
emission reduction	-	5,073.66	8,482.68	8,412.47
BC ratio	-	-2.77	0.67	46.73
incremental cost when reducing one unit emission	-	-0.36	1.49	0.02

Chapter 4 Conslusions

4.1 Conclusion

This paper refers to *ISO/TS 14067:2013* to evaluate the carbon footprints of ICE scooter and the three scooters using different forms of energy, LNG, hydrogen and electricity. And then calculated the life cycle cost and applied cost-benefit analysis to provide the improvement direction for low-carbon energy in scooter application and green transport strategy. The results of this study are as follows

1、Whole life cycle carbon emission

The ICE scooter gave the most carbon footprint over its life cycle, at 0.1418 $kgCO_2$,e/km, while the lowest one was hydrogen scooter, at 0.0169 $kgCO_2$,e/km. Furthermore, the scooters using LNG, hydrogen and electricity lead to emission reductions of about 52.69%, 88.09%, and 87.39% compared to ICE scooter in life cycle. In which, the main emission phase of ICE and LNG scooters were in P2-2, scooter serving-fuel phase at 7,222.30 $kgCO_2$,e (75.00%) and 3,628.44 $kgCO_2$,e (79.64%) emission, respectively. While the main emission phase of hydrogen and electric scooters were in P1, maintenance phase, which emitted 643.20 $kgCO_2$,e (56.07%) and 796.58 $kgCO_2$,e (65.43%) respectively, while they gave no emissions in the P2-2 scooter serving-fuel phase.

2、Life cycle cost assesment

The total life cycle fixed costs, in descending order, were hydrogen scooter ($12,672), LNG scooter ($2,807), electric scooter ($2,396), and ICE scooter ($2,307). While for variable costs, in descending order, were hydrogen scooter ($6,805.71), electric scooter ($4,595.64), ICE scooter ($4,504.60) and LNG scooter ($2,171.61). Thus, the total life cycle cost, in descending order, were hydrogen scooter ($19,477.71), electric scooter ($6,991.64), ICE scooter ($6,811.60) and LNG scooter ($4,978.61). Therefore, the view of the total life cycle cost, LNG scooter had the highest price competitiveness.

3、The result of cost-benefit analysis

This study used the BC ratio between the incremental cost and emission reduction for each fuel-based scooter in comparison to the ICE scooter, to evaluate which scooter had the best energy efficiency. In this part, because both cost and the emission reduction of LNG scooter were better than ICE scooter, so the BC ratio of LNG scooter was -2.77 $kgCO_2$,e/USD, which was the best environmentally friendly scooter, followed by electric scooter and hydrogen scooter with BC rate of 46.73 $kgCO_2$,e/USD and 0.67 $kgCO_2$,e/USD. In which, although hydrogen scooter was best environmentally friendly scooter, its life cycle cost was 2.86 times higher than ICE scooter, much higher than its emission reduction effect, so the BC ratio was only 0.67 $kgCO_2$,e/USD. Therefore, LNG scooter has the best BC ratio, which representing it had the best efficiency in emission reduction.

4.2 Suggestion

According to the result, considering carbon emission reduction and incremental cost, LNG scooter had the best environmental benefits, because both cost and emission were lower than ICE scooter. In addition, although hydrogen scooter had the best carbon reduction benefits, its manufacturing cost was too expensive. Therefore, if hydrogen scooter could store hydrogen in normal temperature and pressure. And also have more better techniques in manufacturing to reduce the fixed cost in the future, which the fixed cost was similar with the ICE scooter, the hydrogen scooter would have more development potential.

4.3 Limitation

In this paper, because some activity data was not easy to estimate, resulting in the assessment of carbon footprint and life cycle cost could not being fully revealed. The limitations of this study are as below

1. carbon footprint of the scooter manufacture

This study explored the whole life carbon footprint of four scooters, focusing on the differences in emission from different energy-based part, however, the differences in scooter manufactures are only from little part such as batteries. Therefore, the study assumes that the production material of the four scooters' manufacturers were the same, excluding the batteries.

2. fuel conversion emission and heat dissipation can not be easily estimated

This study was limited to laboratory equipment, fuel conversion emission and heat dissipation of four scooters could not be fully estimated. Therefore, this study only included the carbon footprint of fuel extraction and manufacturing and fuel consumption.

3. endurance of fuel cell assumes the same

In practice, the endurance of fuel cell would decrease with the usage period of the scooter. While, the data took long time to be estimated, however, the use of the hydrogen scooter was still in a testing phase. Therefore, this study assumed that the whole life cycle endurance of the fuel cell of hydrogen scooter is the same.

4.4 Further Study

Because the above limitations, there are some shortcomings, it is suggested that future research can continue to explore the direction which include: (1) in the future, the research subject can consider the transportation type which emits more emission such as buses, vehicles and trucks, we believe from the viewpoint of cost-benefit, the hydrogen scooter will have the best development potential. (2) when exploring the carbon footprint of different energy-based transport, the life cycle boundary can be set the fuel life cycle (FLC) and vehicle life cycle (VLC), and further apply more detailed data of scooter manufacturing for footprint calculation, then it will be more conducive for related authorities to set the green transport policy.

Chapter 5 Reference

Arteconi, A., Brandoni, C., Evangelista, D., & Polonara. F. (2010). Life-cycle greenhouse gas analysis of LNG as a heavy vehicle fuel in Europe. Applied Energy, 87(2010), 2005-2013.

Bureau of Energy, Ministry of Economic Affairs (2015), carbon emission of fuel combustion report, Retrieved date May 16, 2016 http://web3.moeaboe.gov.tw/ecw/populace/content/wHandMenuFile.ashx?menu_id=363

CAIT Climate Data Explorer, World Resources Institute (2014). Retrieved date March 14, 2016, http://cait.wri.org/indc/#/

Chang, C, C., Wu, F, L., Lai, W, H., & Lai, M, P. (2016). A cost-benefit analysis of the carbon footprint with hydrogen scooters and electric scooters. International Journal of Hydrogen Energy, 41, 30 (2016), 13299-13307.

Environmental Protection Administration, (2015), Greenhouse Gas Reduction and Management Act, Retrieved date May 16, 2016 http://www.epa.gov.tw/public/Data/56178474371.pdf

Environmental Protection Administration, (2015), Taiwan Greenhouse Gas Inventory Executive Summary, Retrieved date May 20, 2016 http://unfccc.saveoursky.org.tw/2015nir/uploads/03_content.pdf

Environmental Protection Administration, (2016), Taiwan Product Carbon Footprint, Retrieved date August 12, 2016 https://cfp.epa.gov.tw/carbon/ezCFM/Function/PlatformInfo/FLFootProduct/ProductGuide.aspx

European Commission, Joint Research Centre (2014). Emission Database for Global Atmospheric Research, Retrieved date March 15, 2016, http://edgar.jrc.ec.europa.eu/overview.php?v=CO_2ts1990-2013&sort=asc1

Gazeo (2017) LPG-powered scooters - can it get any cheaper? Retrieved date May 9, 2017 http://gazeo.com/automotive/vehicles/LPG-powered-scooters-can-it-get-any-cheaper,article,7686.html

Hwang, J. J. (2012). Review on development and demonstration of hydrogen fuel cell scooters. Renewable and Sustainable Energy Reviews, 16(2012), 3803-3815.

Intergovernmental Panel on Climate Change (2014) Climate Change 2014 Mitigation of Climate Change. Retrieved date March 12, 2016, https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_full.pdf

Intergovernmental Panel on Climate Change (2006) Guidelines for National Greenhouse Gas Inventories. Retrieved date March 22, 2016, http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_2_Ch2_Stationary_Combustion.pdf

International Energy Agency (2015) CO_2 Emissions From Fuel Combustion Highlights

2015. Retrieved date March 12, 2016, http://www.iea.org/publications/freepublications/publication/CO_2,EmissionsFromFuelCombustionHighlights2015.pdf

Liberty Times Net (2008), developing Liquefied petroleum gas scooter, Retrieved date Octorber 30, 2016 http://news.ltn.com.tw/news/life/paper/204357

LPG Techniek Van Meenen bvba (2017) Advantages for dealers of LPG Techniek Van Meenen. Retrieved date May 9, 2017 http://www.vanmeenen.com/LPG-autogas-Vlaanderen/LPG-conversion-eng/index2.htm

Ministry of Tranportation and Communications (2014), Summary of traffic statistics indicators, Retrieved date May, 2016 http://www.motc.gov.tw/ch/home.jsp?id=59&parentpath=0,6

Ministry of Tranportation and Communications (2015), Scooter usage survey, Retrieved date May 20, 2016 http://www.motc.gov.tw/ch/home.jsp?id=56&parentpath=0%2C6&mcustomize=statistics101.jsp

Renewable Energy World (2016) Hydrogen Energy. Retrieved date November 20, 2016, http://www.renewableenergyworld.com/hydrogen/tech.html

Shang, J, L., & Pollet, B, G. (2010). Hydrogen fuel cell hybrid scooter (HFCHS) with plug-in features on Birmingham campus. International Journal of Hydrogen Energy, 35(2010), 12709-12715.

United Nations Environment Programme (2016) life cycle assessment. Retrieved date August 14, 2016,

World Bank Group (2016) Carbon Pricing Watch 2016. Retrieved date October 2, 2016,

http://documents.worldbank.org/curated/en/418161467996715909/pdf/105749-REVISED-PUBLIC-New-CPW-05-25-16.pdf