Cost Analysis of Battery-powered Electric Vehicles in Macau

Tze Wood Ching

Department of Electromechanical Engineering, University of Macau, twching@ieee.org

Abstract

The development of electric vehicles (EVs) has advanced rapidly over the past decades. Researchers and engineers have concentrated on the improvement of EV performance through the advances in batteries, motors, converters, controllers and relevant auxiliaries, with great successes. Now, it comes to the stage of commercialization. It is important to understand various cost issues and the business models relating to EV application. This paper aims to discuss the life cycle cost (LCC) of both EV and internal combustion engine (ICE) vehicles in Macau. Viability of EVs will be assessed by comparing the LCCs of a Mitsubishi i-MiEV, and its comparable ICE counterpart "i"; the fuel cost and CO_2 emission reduction of an EV will also be evaluated.

Keywords

electric vehicles, life cycle cost, vehicle performance, carbon dioxide emission, viability

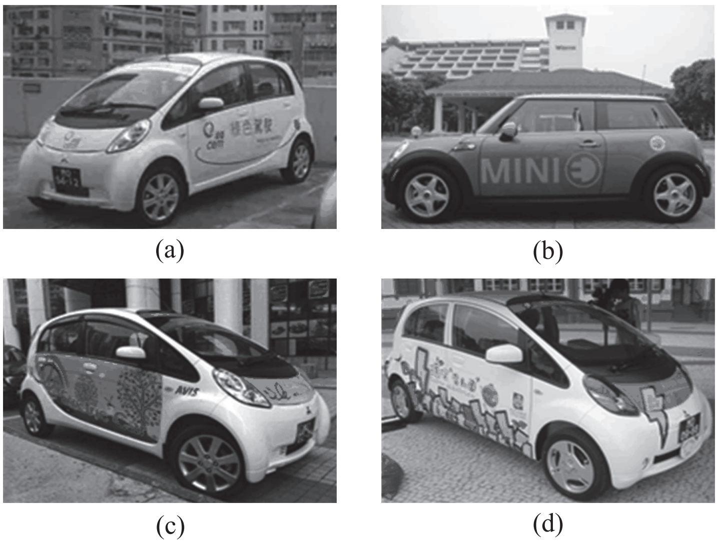
1. INTRODUCTION

With the growing concerns on price fluctuation, depletion of petroleum resources, global warming, environmental and health, there is fast growing interest in electric vehicles (EVs) in Macau and also a pressing need for researchers and power utilities to develop various infrastructures for EVs and strategies for adapting EVs. Being a city with small geographical size (29.5 km^2) limiting the travel range of vehicles, Macau has great potential for EV implementation [Ching, 2010; Ching, 2011; Ching and Lai, 2012].

With an urbanized city and limited land space, Macau has been faced with problems of road congestion and rapid growth in car population. Air pollution is also another important concern. EVs provide low emission urban transportation. Even taking into account the emissions from power plants needed to fuel the vehicles, the use of EVs can reduce carbon dioxide (CO_2) emissions significantly. From the energy aspect, EVs are efficient and environmentally friendly [Chan, 2004; Chan and Wong, 2004; Chan, 2007]. Thus, EVs are promising green vehicles that can reduce both energy consumptions and CO_2 emissions [Wong et al., 2010; Ching, 2011].

2. EVS IN MACAU

In November 2010, the Macau Government announced to promote "Green Vehicles" by offering tax incentives in acquisition of "energy efficient vehicles" [Macao SAR, 2010]. During past two years, several



(a) (b) (c) (d)

Fig. 1 BEVs in Macau: (a) Power Company; (b) For public trial; (c) Car renting company; (d) Macau Government public test rides and demonstrations of electric bikes, scooters, mini/mid-size sedans and buses were conducted by manufacturers from Europe, Japan, Taiwan and China, some of them are shown in Figure 1.

The Macau Government approved in February 2012 to promote "Green Vehicles" by offering 50 % tax reduction (with a limit of MOP 60,000; 1USD ≈ MOP8) in acquisition of energy efficient vehicles [Macao SAR, 2012]. Vehicle import taxes are shown in Table 1. Three battery-powered EVs (BEVs) were imported to Macau, the first by the power company, the second by a car renting company (both in April 2010 and had been running in real-world for more than 32 months); the third was bought by Macau Government in September 2011.

Table 1 Motor vehicle tax (1 USD≈MOP 8)

Vehicle Price (MOP)	Tax
0 – 100,000	0
100,000 – 200,000	40 %
200,000 – 300,000	65 %
300,000 – 500,000	70 %
>500,000	0

A project was launched to investigate the performance of EV, specifically for sub-tropical environment of Macau. Due to the high temperature and humidity, performance of EVs operated in Macau was yet to be understood. Previous experimental studies conducted in the US, Europe or Japan might not reflect the actual local real-road driving conditions. The EV performance study was a collaboration work between the University of Macau (UM) and a local electric power company, Companhia de Electricidade de Macau (CEM), aimed to understand issues relating to EV adoption [CEM, 2010].

A BEV in Fig. 1(a) equipped with a 16kWh battery [Mitsubishi, 2010] was used for experiments and evaluation, while an internal combustion engine (ICE) powered counterpart "i" [Mitsubishi, 2009], was used as baseline. The maximum output of the sample BEV is 47 kW which is the same as "i" with a turbo ICE [Wada, 2010]. Recently, a new model of i-MiEV with a smaller battery of 10.5 kWh (cruising distance reduced from 160 km to 120 km) was launched [Mitsubishi, 2012], their initial purchasing prices together with import taxes (listed in Table 1) were tabulated in Table 2.

The previous experimental works [Ching, 2011] aimed at the road testing of EVs and evaluation of fuel costs and CO_2 reductions when EVs are adopted in Macau area. Road test also revealed that a fuel cost saving of more than 70.4 % could be achieved when both the EV and ICEV were tested under same routes, with results summarized in Tables 3 to Table 4.

3. LIFE CYCLE COST ANALYSIS

It is the most expensive to pay upfront for acquiring an EV, but not the costs for operating and maintaining! To investigate the various costs and the future business models relating to EV application, it was proposed to evaluate the present value of life cycle cost (LCC) [Wong et al., 2010; Ching and Lai, 2012] of an

Table 2 Price of vehicles

	JPY	MOP	MOP (Taxed)
"i" (ICEV)	1,405,714	137,749	152,829
i-MiEV (16 kWh)	3,619,048	354,639	437,887
i-MiEV (10.5 kWh)	2,476,191	242,648	276,508

Table 3 Fuel cost and consumption

	EV (MOP)	ICE (MOP)
Fuel price	1.223 per kWh	9.85 per Liter
Fuel consumption	0.1469 kWh per km	0.0616 Liter per km
Fuel cost per distance travelled	0.1797 per km (29.6 %)	0.6068 per km (100 %)

Table 4 Comparison of CO_2 emissions

Electricity generation	EV	ICE
383.16 g/kWh	56.278 g/km (48.1 %)	117 g/km (100 %)

Table 5 Operating and maintenance costs

	EV (MOP)	ICE (MOP)
Engine oil	–	2,000 (every 5,000 km)
Tires	2,000 (every 36,000 km)	2,000 (every 36,000 km)
Routine maintenance	1,000 (every 12,000 km, after 60,000 km)	5,000 (every 12,000 km, after 60,000 km)
Battery (12 V)	500 (every 36,000km)	500 (every 36,000km)
Vehicle circulation tax	–	850 per year
Fuel	0.1469 kWh per km	0.0616 Liter per km

EV and compare with an ICE vehicles.

3.1 Upfront costs and taxes

In Macau, the motor vehicle tax (Table 1) was already included in the vehicle purchase price listed by a dealer (Table 2), but the owners are required to pay the vehicle circulation tax annually (Table 5), which will be waived for EVs in Macau.

3.2 Operating and maintenance (O&M) costs

Acquisition cost of EVs is high. However, EVs are much more efficient than ICE vehicles [Ching, 2011], their o&m costs are also much lower. Various maintenance and operating costs for ICEV and EV are compared in Table 5.

3.2.1 Forecast of gasoline price

Historical quarterly price of gasoline from Q4/2008 to Q4/2011 [DESC, 2012] was used to forecast the future gasoline price from 2012 to 2021, using equations (1)-(3) below, as y is the forecast for period t:

$$y_t = a + bt \tag{1}$$

where

$$b = \frac{n\Sigma ty - \Sigma t \Sigma y}{n\Sigma t^2 - (\Sigma t)^2} \tag{2}$$

and

$$a = \frac{\Sigma y - b\Sigma t}{n} \tag{3}$$

Similarly, historical yearly electricity prices [DESC, 2012] from 2007 to 2011 were used to forecast the future electricity price from 2012 to 2021, using the same decomposition approach. Parameters a, b and forecasting accuracy were to be further investigated and analyzed in the future. Results of forecasted prices of gasoline and electricity are shown graphically in Figure 2 and Figure 3 respectively.

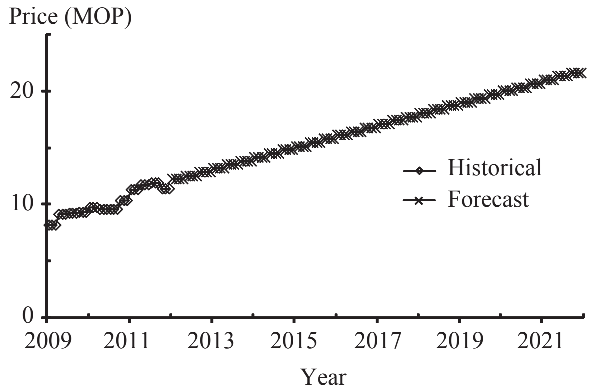


Fig. 2 Prices of gasoline in Macau

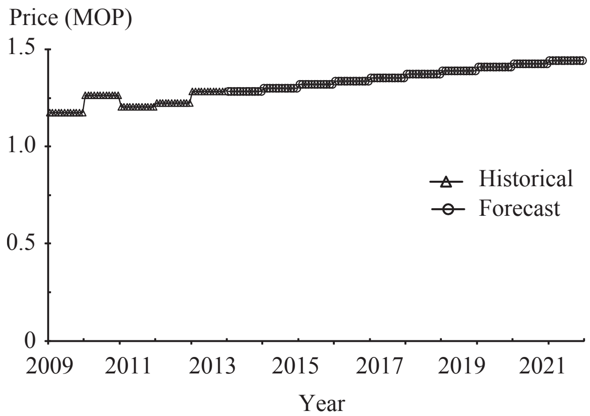


Fig. 3 Prices of electricity in Macau

3.2.2 Present value of o&m costs

Expenditures for o&m are to be happened in the future, for example, the monthly fuel consumption costs are to be settled monthly. When comparing the LCCs, the present values of future expenditures are evaluated using equation (4):

$$P = \frac{F}{(1+i)^n} \tag{4}$$

where:

P = present value of expenditure

F = future expenditure
i = interest rate (2.81 % in 2011)
n = interest compounding period

3.3 Costs to consumer

LCCs are the summation of all costs mention in sections 3.1 to section 3.2 (upfront cost listed in Table 2 and o & m costs tabulated in Table 5), over the lifetime of the vehicles. By assuming both the ICEV and EVs are to be used in Macau, and assuming a monthly driving range of 1000 km, all costs listed in Tables 1-2 incurred during the ten years of operation were calculated and listed in Table 6 and plotted in Figure 4.

From Table 6, after 120 months of operation, the total costs of an ICEV will be MOP340,062 while it is higher than MOP308,593, the total costs of an EV equipped with 10.5kWh battery. From Figure 4, the break-even time for these two vehicles was estimated to be at the 100th month of operation, i.e. April 2020. Since options for battery maintenance and replacement are not available in Macau, additional costs may incur in the future.

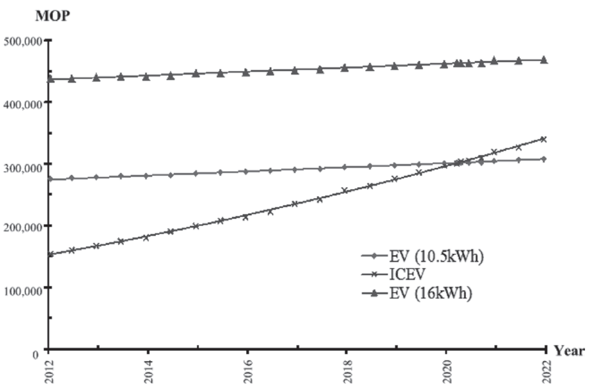


Fig. 4 Present values of LCC for 3 vehicles

4. CONCLUSION

A cost model has been developed to calculate various costs to be incurred during the ten years of operation of two BEVs, and a comparable ICEV "i" was used as a benchmark. Their acquisition cost, taxes, Government Incentives, the present values of their future operation and all external costs are estimated and compared. Fuel consumption data and costs obtained in previous experimental studies were utilized in this exercise and their future prices were forecasted using linear decomposition approach.

Results obtained from this LCC study are the cost savings from monthly fuel consumption and various maintenance expenditures will compensate the high upfront initial cost of the EV being studied, the break-even time was estimated to be 100 months in Macau's context. Furthermore, CO_2 displacement can be reduced (as compared in Table 4) by 6072 kg during that 100 months period with monthly driving range of 1000 km. Additional reduction could be achieved when more renewable energy sources or non-coal electricity was used for the generation of electricity.

EVs are clean due to their zero local emissions and low global emissions. They are also green due to their environmental friendliness, since electricity can be generated by renewable energy sources to achieve sustainable mobility and zero emissions [UBC, 2010].

Acknowledgements

This paper was supported by the Research Council of the University of Macau under MYRG041(Y1-L1)-FST12-TWC and CG086- FST2012-CTW.

The author gratefully acknowledge Mr. K. Lai & L.

Table 6 Present values of LCCs (MOP)

	"i" (ICEV)	i-MiEV (16 kWh)	i-MiEV (10.5 kWh)
Purchase	152,829	437,887	276,508
12th month	166,745	440,115	278,737
24th month	180,965	442,311	280,933
36th month	199,621	446,774	285,396
48th month	214,361	448,907	287,529
60th month	235,429	451,878	290,499
72th month	256,928	456,906	295,527
84th month	276,395	459,767	298,388
96th month	297,522	462,574	301,195
108th month	318,995	467,270	305,891
120th month	340,062	469,972	308,593

Iong of UM and Mr. P. Diniz, of CEM for their supports and assistance on this study.

References

CEM, EV study in Macau, http://www.cem- macau.com/CEM-signs-protocol-with-University, 2010.

Chan, C. C., The state of the art of electric vehicles, *Journal of Asian Electric Vehicles*, Vol. 2, No. 2, 579-600, 2004.

Chan, C. C., and Y. S. Wong, Electric vehicles charge forward, *IEEE Power & Energy Magazine*, 25-33, 2004.

Chan, C. C., The state of the art of electric, hybrid, and fuel cell vehicles, *Proceedings of the IEEE*, Vol. 95, No. 4, 704-708, 2007.

Ching, T. W., Electric vehicle charging station in Macau, *World Electric Vehicle Journal*, Vol. 4, 677-684, 2010.

Ching, T. W., Road testing of electric vehicle in Macau, *Journal of Asian Electric Vehicles*, Vol. 9, No. 2, 1491-1495, 2011.

Ching, T. W., and K. Lai, Life cycle cost analysis of battery-powered electric vehicles in Macau, *Proceedings of the International Conference on Electrical Engineering*, 1340-1344, 2012.

DESC, Statistic (Balance of energy), http:// www.dsec.gov.mo/Statistic.aspx, 2012

Macao SAR, Policy address for the fiscal year 2010, http://portal.gov.mo/web/guest/info_detail?infoid=15947, 2010.

Macao SAR, Macau Law No. 1-2012, http:// http://images.io.gov.mo/bo/i/2012/06/lei-1-2012.pdf, 2012.

Mitsubishi, Features of T, http:// www.mitsubishi-motors.co.jp/i/grade/gra_01.html, 2009.

Mitsubishi, Features of G, http:// www.mitsubishi-motors.co.jp/i-miev/grade/gra_01.html, 2010.

Mitsubishi, Features of M, http:// www.mitsubishi-motors.co.jp/i-miev/grade/gra_02.html, 2012.

UBC, UBC electric car first to beetle across Canada, http://www.publicaffairs.ubc.ca/2010/ 08/30/ubc-electric-car-first-to-beetle-across-canada, 2010.

Wong, Y. S., W. Lu, Z. Wang, and Y. Liu, Life cycle cost analysis of different vehicle technologies in Singapore, *The 25th World Battery, Hybrid and Fuel Cell Electric Vehicle Symposium & Exhibition*, CD-Rom, 2010.

Wada, K., Further Evolution Towards a new generation of electric vehicles i-MiEV", *Journal of Asian Electric Vehicles*, Vol. 8, No. 2, 1405-1408, 2010.

(Received November 29, 2012; accepted December 20, 2012)