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Life Cycle Cost Analysis of Different Vehicle Technologies in Singapore

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Abstract

Singapore is a diamond-shaped island with several surrounding smaller islets. It has a flat coastline with a land area of 710 km² in 2009. With a highly urbanized city and limited land space, Singapore has been faced with problems of road congestion and rapid growth in car population. Electric vehicles (EVs) provide low emission urban transportation. Even taking into account the emissions from power plants needed to fuel EVs, the use of EVs still reduce carbon dioxide emissions significantly. From the energy aspect, EVs are efficient. EVs are promising alternative fuel vehicles that can reduce energy consumptions and carbon dioxide emissions in Singapore. A life cycle cost model was built to calculate life cycle costs of EVs and internal combustion engine cars in Singapore. It was found that EV is the most expensive car under current Green Vehicle Rebate scheme. The EV will be economically viable in Singapore if there is a breakthrough at batteries to cut EV prices.

Keywords: Cost benefit analysis, energy efficiency, environmental impact, life cycle cost analysis

1 Introduction

Singapore is a diamond-shaped island with several surrounding smaller islets. It has a flat coastline with a land area of 710 km² (2009). With a highly urbanized city and limited land space, Singapore has been faced with problems of road congestion and rapid growth in car population. Car population was increased from 371 to 540 thousands from 1998 to 2008. However, the average daily driving range of cars is less than 58 km as shown in Figure 1. Transport solutions can play a critical role in improving Singapore's state of energy efficiency. To improve energy efficiency on the move, Singapore government promotes the use of public transport, promote the use of more energy efficiency vehicles and ease traffic congestion for better fuel economy.

Electric vehicles (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 [1-4]. Thus, EVs are promising alternative fuel vehicles that can reduce energy consumptions and CO_2 emissions.

Upfront cost of EVs is high. However, EVs are more efficient than internal combustion engine (ICE) cars. Thus, running and maintenance costs of EVs are lower. The carbon emissions are lower as well. A life cycle cost (LCC) model has been developed to calculate upfront, operation and external costs of EVs and comparable ICE cars in Singapore's context.

This paper aims to discuss LCCs of EV and ICE car in Singapore. Viability of EVs will be assessed by comparing LCCs of Mitsubishi i-MiEV and four comparable ICE and hybrid cars.

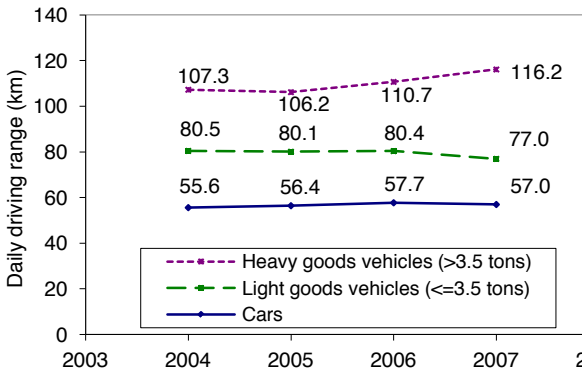

Figure 1: Vehicle daily driving range.

2. Life Cycle Cost Model

There is no car manufacturing industry in Singapore. The LCC model in this paper refers to the assessment of upfront, operation and external costs of cars in Singapore. Societal and consumer life cycle costs are key outputs of the model.

Societal life cycle cost (SLCC) is sum of vehicle upfront cost excluding tax, operation cost excluding tax and external cost as illustrated in Figure 2. External cost is the incurred costs of direct and indirect long-term economic, social and environmental impacts from vehicles. SLCC does not include certain taxes, which are used for benefit of the society. Thus, SLCC is the price for service of transportation. Consumer life cycle cost (CLCC) is sum of vehicle upfront cost with tax and operation cost with tax. CLCC is the cost borne by consumers. Both SLCC and CLCC are useful for cost-benefit analysis (CBA) and for assessment of taxation schemes on vehicles [5].

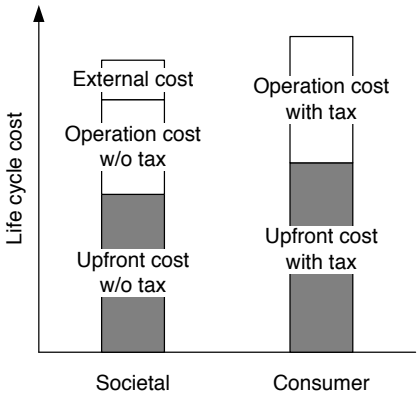

Figure 2: Societal and consumer life cycle costs.

2.1 Upfront Cost

The upfront cost of a car in Singapore consists of open market value (OMV), excise duty (ED), goods & service tax (GST), registration fee (RF), additional registration fee (ARF) and Certificate of Entitlement (COE) fee [1].

2.1.1 Open Market Value

The OMV of a car is assessed by the Singapore Customs, based on the price actually paid or payable for the goods when sold for export to the country of importation. This price includes purchase price, freight, insurance and all other charges incidental to the sale and delivery of the car to Singapore.

2.1.2 Excise Duty

Motor vehicles are dutiable goods subject to Singapore Customs and excise duties in Singapore. The ED for motor vehicle is 20% of the OMV.

2.1.3 Goods and Service Tax

The moment goods are imported into Singapore, they are subject to GST. GST is administered by the Inland Revenue Authority of Singapore (IRAS) and collected by Singapore Customs. GST on imports of motor vehicle is 7% of the vehicle's OMV and Customs Duty [1].

2.1.4 Certificate of Entitlement Fee

The COE has been instituted by the Government since May 1990. COE is a program designed to limit car ownership, and hence, the number of vehicles on the country's roads. The COE system requires car buyers to bid for the right to buy a motor vehicle, with the number of certificates deliberately restricted. The COE allows holders to own a car for a period of 10 years, after which they must either scrap or export their car with financial incentives, or bid for another COE at the prevailing rate then if they wish to continue using their cars for further 10 years.

There are 5 categories of COE as listed in Table 1. COE fee (COEF) varies monthly. The COEF for Category A was set SGD 20,802 and that of Category B was set at SGD 26,389 in calculating car costs.

2.1.5 Registration and Additional Registration Fees

The vehicle RF is fixed at SGD 140 while the ARF is 100% of vehicle's OMV.

2.1.6 Green Vehicle Rebate Scheme

The green vehicle rebate (GVR) scheme offers incentives to promote green vehicles which are more fuel-efficient and emit less air pollutants than their conventional petrol or diesel equivalents. The GVR scheme was first introduced in January 2001

for the registration and use of electric and hybrid cars to encourage the use of green vehicles. It was later extended to compressed natural gas (CNG) vehicles in October 2001. The GVR scheme has been extended to include imported used electric and hybrid vehicles.

New cars using electric, petrol-electric, CNG or petrol-CNG propellant registered between 1 October 2006 and 31 December 2011 are eligible for ARF rebate of 40% of OMV under the GVR scheme.

Table 1: Categories of COE.

Non-transferable categories	
Category A	Cars (1,600cc and below) & taxis
Category B	Cars (1,601cc and above)
Category D	Motorcycles
Transferable categories	
Category C	Goods Vehicles and Buses
Category E	Open Category

2.1.7 Transport Technology Innovation and Development Scheme

The Transport Technology Innovation and Development Scheme (TIDES) aims to attract and nurture high value, knowledge-based manufacturing and research activities in Singapore. Vehicles used for the sole purpose of conducting research and development, including test-bedding activities are eligible for TIDES. COEF, RF, ARF, RT and ED of vehicles are exempted under the TIDES. Instead of RT, a license fee of SGD 1,600 per year is needed for the "Special Purpose Licenses" for vehicles under the TIDES.

2.2 Operation Cost

Operation costs of running a car in Singapore consist of road tax (RT), radio license fee (RLF), car insurance cost (CIC), parking fee (PF), fuel cost (FC), tire cost (TC), service cost (SC) and fee charged by the Electronic Road Pricing (ERP) system. [1].

2.2.1 Electronic Road Pricing System

The Electronic Road Pricing (ERP) system is one measure to tackle traffic jams during peak hours. ERP is an electronic system of road pricing based on a pay-as-you-use principle. It is designed to be a fair system as motorists are charged when they use the road during peak hours. ERP has been extended to choke-points on expressways and major roads to alleviate congestion.

The Land Transport Authority (LTA) reviews the traffic conditions on the expressways and roads, where the ERP system is in operation, on a quarterly basis and during the June and December school holidays. After the review, the ERP rates would then be adjusted where necessary to minimize congestion on the roads. ERP has been effective in maintaining an optimal speed range of 45 to 65 km/h for expressways and 20 to 30 km/h for arterial roads.

2.3 External Cost

External cost is the pollution cost of vehicular emissions. The pollution costs are calculated by multiplying amount of pollutant over the lifetime with the unit damage cost of the pollutant.

2.4 Model Assumptions

Societal and consumer life cycle costs compose of upfront costs and discounted present values (DPVs) of operation and external costs over the lifetime. DPV is the present worth of costs occurring in the future years by discounting the time value with a real discount rate. Table 2 lists vehicle service life, annual driving range and the real discount rate. RT and GST are assumed to be used for benefit of the society.

Table 2: Model parameters.

Parameters	
Vehicle service life (year)	10
Annual driving range (km)	21,170
Real discount rate	0.02

3. Life Cycle Costs of EVs in Singapore

Singapore is receptive to the prospect of EVs. An EV Taskforce, chaired by the Energy Market Authority (EMA) and LTA has been set up to assess the benefits and applicability of adopting EVs in Singapore.

The EV test-bedding programme involves key industry players to examine infrastructure requirements and new business models arising from EVs, as well as to identify industry and R&D opportunities. The test-bed is open to all auto manufacturers and technology companies interested in shaping the future of electric transport. The first batch of up to 50 EVs will arrive in early 2011. Mitsubishi Motor Corporation is a key industry player of the test-bedding programme.

The LCC of Mitsubishi i-MiEV is calculated and compared with those of ICE and hybrid cars

with engine displacements in between 1,000 cc and 2,000 cc. LCCs of Toyota Corolla, Prius, Camry and Camry Hybrid are calculated for assessment of viability of EVs in Singapore. Figure 3 shows the i-MiEV while Table 3 shows i-MiEV's specifications.

Figure 3: Mitsubishi i-MiEV

Table 3: Powertrain specification of i-MiEV.

Motor	
Type	Permanent magnet synchronous
Max. power (kW)	47
Max. torque (Nm)	180
Battery	
Type	Lithium-Ion
Range in Japan 10.15 mode cycle (km)	160
Top speed (km/h)	130

Table 4 shows engine displacements and OMVs of the remaining ICE and hybrid cars.

Table 4: car engine size and OMV.

Car Model	**Engine capacity (cc)**	**OMV (SGD)**
Toyota Corolla	1794	19,827
Toyota Prius	1798	35,505
Toyota Camry	2362	29,248
Toyota Camry Hybrid	2362	39,456
Mitsubishi i-MiEV	Not applicable	88,000

3.1 Upfront Costs

The i-MiEV, Prius and Camry Hybrid are eligible for the GVR. The i-MiEV is also eligible for the TIDES during the EV Test-bedding period. Table 5 shows breakdowns of i-MiEV's upfront costs under the GVR scheme and the TIDES. Figure 4 shows societal and consumer life cycle costs of all the cars.

3.2 Operation and External Costs

Fuel cost and carbon cost depend on driving range and fuel economy. The annual driving range is 21,170 km and the average fuel economies of cars in urban and highway driving cycles is used to calculate LCCs. Table 6 shows the car fuel economies and annual CO_2 emissions at source of the fuels. Electricity for EV is assumed to be generated by natural gas in combined cycle gas turbine (CCGT) power plants and transmitted with an aggregated efficiency of 49.92%. Gasoline price is SGD1.77 per liter and electricity price is SGD 2.5 per vehicle-km. Figure 5 shows annual societal and consumer operation costs. Carbon cost is assumed to be 80 SGD (40 Euro) per tonne and the annual carbon costs is shown in Figure 6.

Table 5: upfront costs of i-MiEV.

Upfront costs	**GVR scheme**	**TIDES**
OMV (SGD)	88,000	88,000
ED (SGD)	17,600	0
GST (SGD)	7,932	6160
ARF (SGD)	88,000	0
RF (SGD)	140	0
GVR (SGD)	-35,200	0
COEF (SGD)	26,389	0

3.3 Discussions

Singapore government regulates car population and mitigates traffic congestion by raising the upfront cost and costs of driving. Driving range in Singapore is short such that the external cost of a single car is small. Only RT and GST are assumed to be used for benefit of the society such that CLCCs of all cars are higher than their SLCCs. Figure 7 shows breakdowns of the SLCCs and Figure 8 shows breakdowns of the CLCCs.

The CLCC is a key parameter in assessing the niche market for EVs in Singapore. Figure 9 shows LCCs of the cars in ascending order of CLCC. The i-MiEV is the second cost effective car after the Corolla under the TIDES, however, it is the most expensive car under the current GVR scheme. EV will be economically viable in Singapore if there is a breakthrough at the batteries to diminish OMV of the EV. The Government can enhance current taxation schemes on vehicles to lessen upfront costs of EVs.

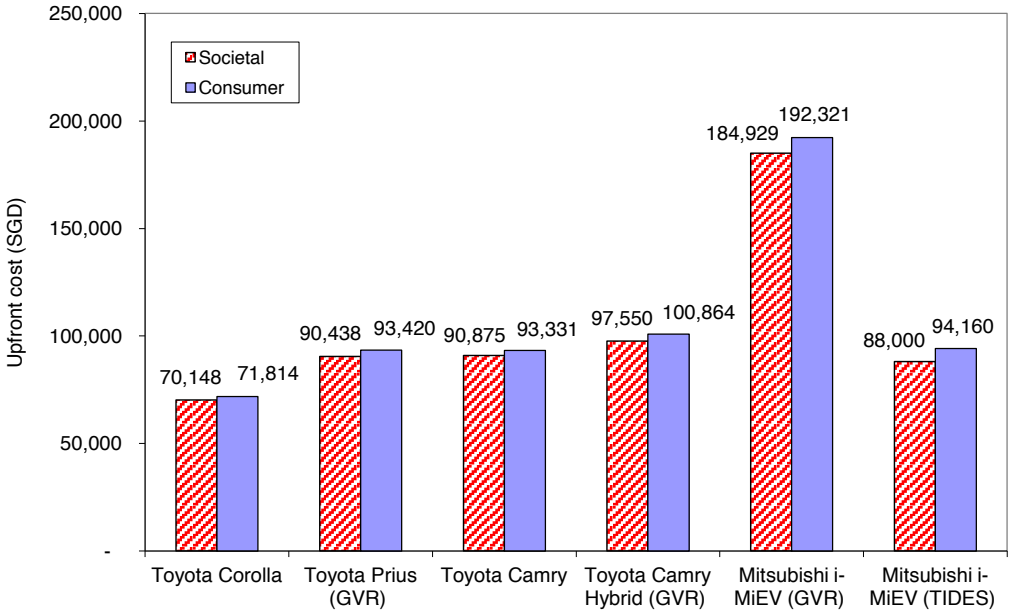

Figure 4: Societal and consumer upfront costs.

Table 6: Vehicle fuel economy and CO_2 emissions.

Car Model	P2W[(a)] energy consumption (Lge[(b)]/100km)	S2P[(c)] efficiency	S2W[(d)] energy consumption (Lge/100km)	S2W carbon intensity (g CO_2/km)	Annual CO_2 emission (Tonne)
Toyota Corolla	7.38	1	7.38	162.36	3.44
Toyota Prius	4.8	1	4.80	105.6	2.24
Toyota Camry	9.4	1	9.40	206.8	4.38
Toyota Camry Hybrid	7.025	1	7.03	154.55	3.27
Mitsubishi i-MiEV	2.12	0.4992	4.25	75.47	1.60

Remark:
(a)P2W: Tank to Wheel
(b) Lge : Liter of gasoline equivalent
(c) S2P: Well to Tank
(d) S2W: Well to Wheel

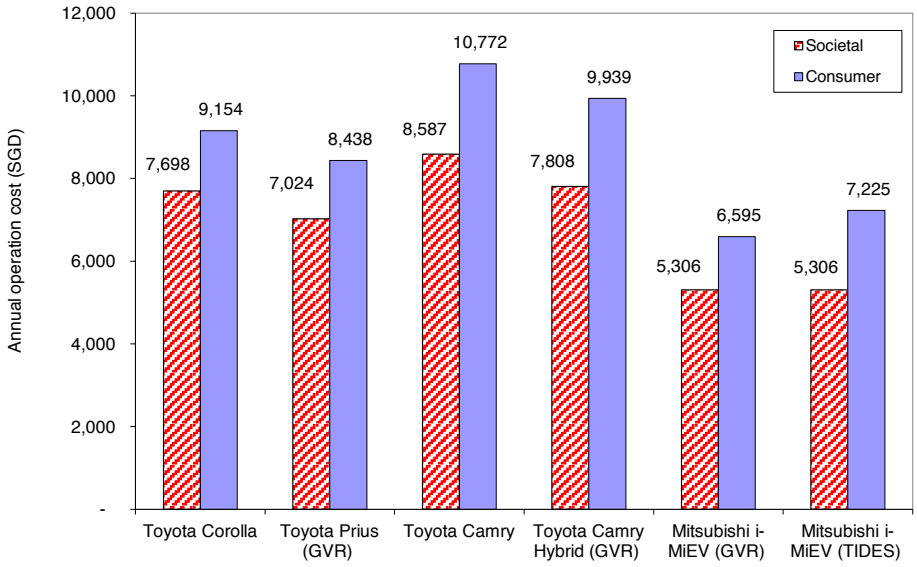

Figure 5: Annual societal and consumer upfront costs.

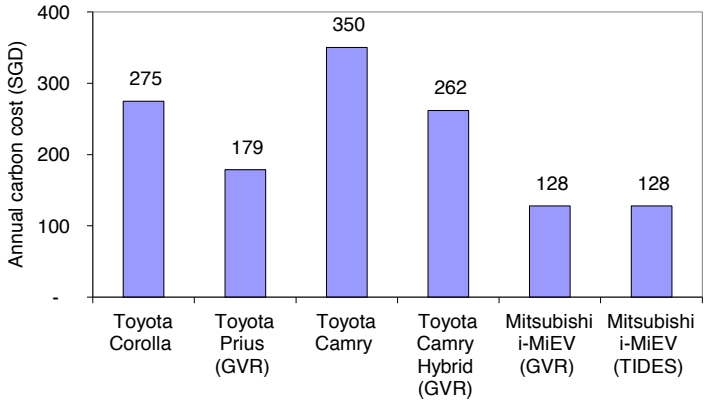

Figure 6: Annual carbon costs.

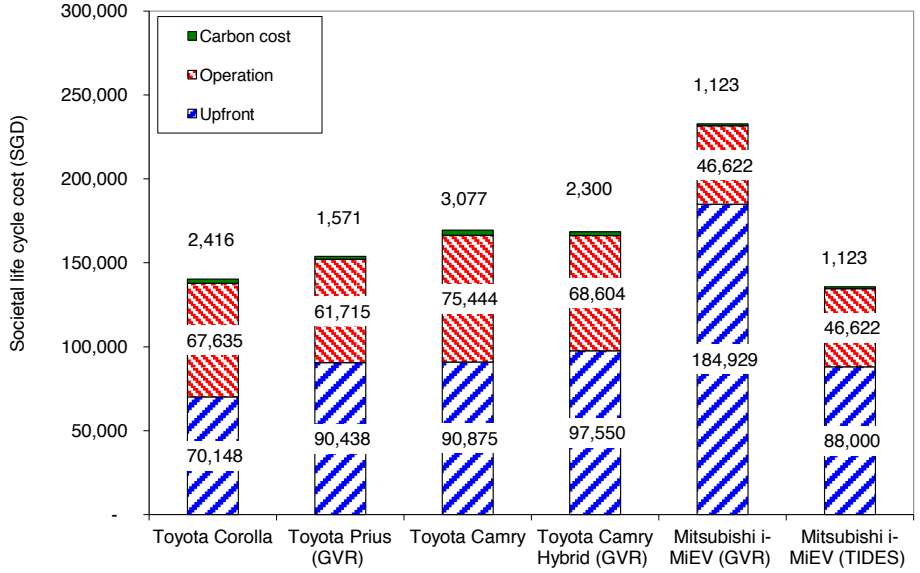

Figure 7: Societal life cycle costs.

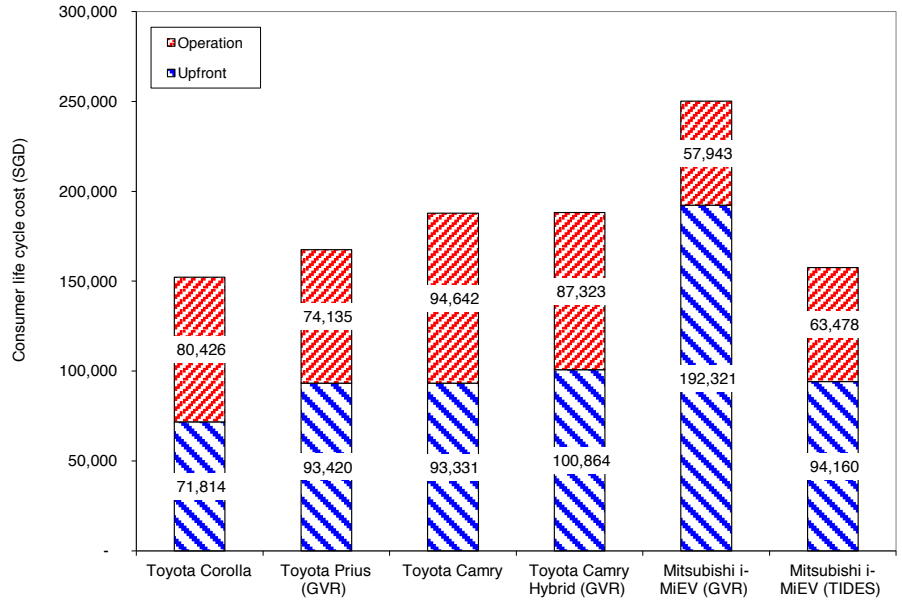

Figure 8: Consumer life cycle costs.

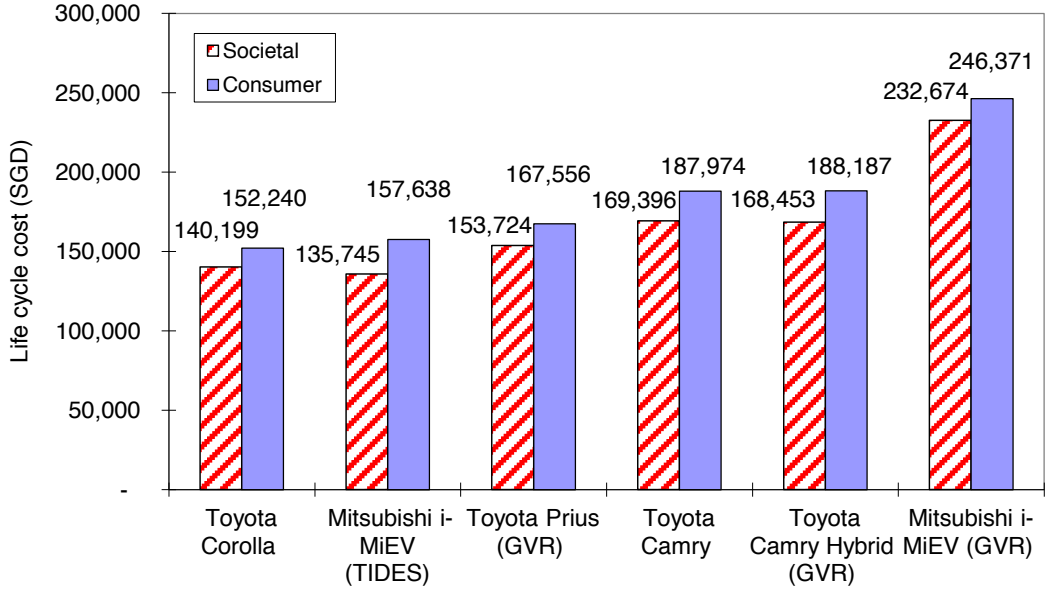

Figure 9: Societal and consumer life cycle costs.

4. Conclusions

The life cycle cost model for assessment of viability of EVs in Singapore was discussed. It was found that the EV is the most expensive car under current GVR scheme. EVs will be economically viable if there are breakthroughs at batteries to lessen EV prices. The Government can enhance current vehicle taxation schemes to reduce EV life cycle costs.

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