Low Carbon Economy

Volume I

Shania Gomes

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Volume I

Edited by **Shania Gomes**

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Volume I

Preface

As the term clearly suggests, Low Carbon Economy refers to an economy that has a minimal output of greenhouse gas emissions, specifically focussing on carbon dioxide emissions. Greenhouse gases, such as carbon dioxide, methane, water vapour etc., allow direct sunlight to reach the Earth's surface uninterrupted. This allows only limited heat to escape back to space, thereby trapping it in the lower atmosphere. Scientists are concerned about the negative impacts of greenhouse gases such as carbon dioxide due to climate changes.

The origin of the concept of Low Carbon Economy can be traced to the year 1972 in Stockholm, at the inaugural UN Conference on the Human Environment. In this direction, a prominent step was the signing of the Kyoto Protocol. The Kyoto Protocol came into force on February 16, 2005, under which most industrialized countries committed themselves to reduce their carbon emissions.

Keeping the present scenario in mind, a Low Carbon Economy is crucial to the society, in order to avoid catastrophic climatic changes. Moreover, it would also help keep in check the use of fossil fuels and has led to a growing emphasis on using renewable sources of energy. An economy majorly based on renewable energy and a carbon-free society would definitely slow down the present rate of climate change.

I would like to thank all the contributors for being a part of this book by sharing their valuable work. I would also like to thank my family for cooperating with me at every step.

Editor

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China' New Energy Passenger Vehicle Development Scenario Analysis Based on Life Time Cost Modelling

Xunmin Ou[1,2*], Qian Zhang[1,2], Xu Zhang[1,2], Xiliang Zhang[1,2]

[1]Institute of Energy, Environment and Economy, Tsinghua University, Beijing, China; [2]China Automotive Energy Research Center, Tsinghua University, Beijing, China.

ABSTRACT

Based on the analysis on the development trend of vehicle technology, vehicle price, vehicle fuel economy and fuel supply price, the new energy vehicle (NEV) passenger car development scale is projected on different scenario with the application of life time cost model. Three scenarios are set to find electric vehicle (EV) and fuel cell vehicle (FCV) development potential in future to their pessimistic and optimistic assumptions in China. The results are demonstrated: 1) NEV development needs a long time due to high initial cost for vehicle buyer; 2) EV will develop quickly under if there is quick development of battery technology; and 3) FCV can only develop in a large scale in 20 - 30 years even in the optimistic scenario.

Keywords: Life Time Cost; New Energy Vehicle; Scenario Analysis; China

1. Introduction

As the energy security and Greenhouse gas (GHG) emission issues are becoming urgent in transport sector in China, new energy vehicle (NEV) is considered as one of best options of reducing petroleum and GHG in this sector in China from the long term.

NEV development has been supported by a series of initiatives in China. But the scale of NEV is still on the small level and the enthusiasm of vehicle buyers to NEV is still low due to some reasons and one of them is the high cost issue.

Generally, compared to the conventional gasoline and diesel vehicle, the NEV will consume the owner lower fuel costs and lower maintenance and repair costs, but in the current stage, the higher initial costs and higher insurance costs have been unbeatable evils that eat up buyers' plan for NEV buying and holding [1].

Electric vehicles and FCVs represent an important innovation in new energy vehicle technologies. As with other technological innovations, the promotion of EV and FCV require three stages, and their penetration rate displays an S-shaped curve [2].

So it is urgent to find: 1) what are both the real current and projected situation of buying and operating NEVs from the perspective of their lifetime; and 3) some useful options to improve the situation of high cost for NEVs and promote their large scale development as soon as possible.

In this paper, the lifetime costs of the pathways of new energy vehicles are assessed by the application of the life-cycle cost (LCC) model with the conventional gasoline vehicle as baseline vehicle to be compared; the future situations are estimated in different scenarios and some key factors affecting the final results are assumed and tested; At last, some concluding remarks are given on some discussion.

2. Methodology

2.1. Framework of LCC Module

For the vehicle owner, the total cost (TC) of owning and operating one certain type of vehicle is the sum of two part of sub-section: initial cost (IC) of buying the vehicle and all other operating-related cost (OC, including all types of tax and fees, fuel cost, inspection and maintenance, repair cost and others) which is related to operate the vehicle, as the following equation (Equation (1)) shows [3,4].

$$TC = IC + OC \quad (1)$$

*Corresponding author.

Here we can use manufacturer's suggested retail price (MSRP) as one of alternative options of the IC of vehicle. And as Equation (2) shows, the OC of vehicle can be divided into two parts which are energy-related cost (EC) and non-energy-related cost (NEC).

$$OC = EC + NEC \quad (2)$$

2.2. Calculation Methods from the Owner Perspective

For IC of EV and FCV, they are calculated by adding the additional cost, which is price premium actually, to the IC of baseline vehicle pathway which is conventional gasoline vehicle in this article. The compared vehicles are based on similar transportation capacity.

For the fulltime EC, it is calculated by multiplying the energy cost per unit and the energy consumption amount during the fulltime.

For the fulltime NEC category, all the operating and maintenance costs excluding energy are categorized, including registration, tax, insurance, maintenance, repair, tires, lubricant oil, safety- and emission-inspection fees, parking, and tolls.

Detailed and actual data in these specific categories are collected and analyzed to get the scientific and correct results for LCC of vehicle.

3. Key Assumption and Data

3.1. Key Assumptions for Vehicle

3.1.1. Segments of Passenger Vehicle

The segments were divided for passenger vehicle (PV) in the model: According to displacement of engine, PV is further divided into Micro, Small, Medium and Large segments as **Table 1** shows.

3.1.2. VKT of Passenger Vehicle

Here it assumes VKT of Micro-size vehicle drops rapidly, because more Micro cars become the second car of a family or the special car for commuting in working days, hence the average travel times or travel distance each trip will drop quickly [5-7], as **Table 2** shows.

3.1.3. Future Cases for Vehicle and Battery Technology

Two cases are also set up for future scenario of energy unit cost and the corresponding energy efficiency of vehicle and power battery cost reduction. In the base case, fuel price will have a moderate increasing rate and fuel economy of vehicle will be improved in a moderate trend correspondingly, and power battery cost will be decreased slowly; In the alternative case, fuel price will have a quick increasing rate and fuel economy of vehicle will be improved in a tremendous trend correspondingly, and power battery cost will be decreased quickly.

3.2. Key Data for MSRP of Vehicle

3.2.1. ICE Vehicle

In 2010, the MSRPs of vehicle in the four sub-segments are listed in **Table 3**. It is estimated that the conventional car MSRP will not be changed for many years to 2050 though the technology will be improved but the feedstock and materials will encounter the increasing supply price.

Here it presumes MRSP of ICE PVs keeps steady by 2050, based on the constant prices of 2010. There are price-up reasons: 1) Labor and material cost will further rise in China; while 2) HEV and other new technology to improve FE will cost more, as well as stricter emission control. The Price-down reason is China Auto market will further expand to bring up advantages of scale up to reduce vehicle cost.

3.2.2. EV

For EV, the additional cost to the baseline car' MSRP is majorly the cost of battery system, but the difference between ICE vehicle and EV without battery system is also factor for the final MSRP. Here the mark-up costs are included for all the vehicles.

The battery system cost for EV will be different in future between Base case and Alternative case, as **Table 4** shows.

Table 1. Passenger vehicle division.

Division	Displacement of engine
Micro	<1.0 L
Small	1 ~ 1.6 L
Medium	1.6 - 2.5 L
Large	>2.5 L

Table 2. VMT of passenger vehicle (km/year).

	2010	2020	2030	2040	2050
Micro	14,000	12,000	10,000	8000	6000
Small	16,000	14,000	13,000	12,000	11,000
Medium	18,000	16,000	14,000	13,000	12,000
Large	20,000	18,000	15,000	14,000	13,000

Table 3. MRSP of ICE PVs.

	MRSP (RMB)
Micro	35,000
Small	120,000
Medium	223,700
Large	535,400

While battery capacities are varied to each sub-segment of PV, as **Table 5** shows.

What's more, the differences between ICE vehicle and EV without battery system are also different in future between base case and alternative case, as **Tables 6** and **7** show: in the base case there are slow progresses of EV technology, while in the alternative case there are quick progresses of EV technology.

3.2.3. FCV

Similarly, for FCV, the final MSRPs are projected as ratios: MRSP of FCV divided by MRSP of ICE. **Tables 8** and **9** show the different cases: in base case, there are slow progresses for FCV while in alternative case there are quick progresses for FCV.

Table 4. Battery system cost of EV (RMB/kWh).

	2010	2020	2030	2040	2050
Base case	6000	4800	4000	3500	3000
Alternative case	6000	2500	2143	2143	2143

Table 5. Battery capacity of EV PV (kWh).

	2010	2020	2030	2040	2050
Micro	8	7	7	6.5	6.2
Small	13	13	13	13	13
Medium	18	18	18	18	18
Large	24	24	24	24	24

Table 6. Difference between MRSP of EV without battery system and ICE car in the base case.

	2010	2020	2030	2040	2050
Micro	10,150	0	0	0	0
Small	34,800	0	0	0	0
Medium	64,873	0	0	0	0
Large	155,266	0	0	0	0

Table 7. Difference between MRSP of EV without battery system and ICE car in alternative case.

	2010	2020	2030	2040	2050
Micro	6650	2450	(3500)	(7000)	(8400)
Small	2280	(5560)	(7800)	(32,486)	(35,194)
Medium	1214	5832	(2393)	(12,125)	(21,000)
Large	98,793	48,120	19,894	(5267)	(29,571)

Notes: Bracket () means negative value.

3.3. Key Data for Energy Efficiency of Vehicle

3.3.1. Fuel Economy of ICE Passenger Vehicle

As we all know, the fuel consumption in real operating conditions is about 15% higher than in laboratory tests for inner combustion engine (ICE) vehicles and about 30% for the electric drive mode [5-7].

As **Tables 10** and **11** show, in Base Case and Alternative Case, fuel economy of ICE improvement is different. It assumes that Micro, Small, Medium and Large portion in PV fleet is constant, taking percentage of 30%, 50%, 10% and 10%, respectively. The fleet average fuel economy of new sales can be calculated by the weight

Table 8. MRSP of FCV divided by MRSP of ICE in base case.

	2010	2020	2030	2040	2050
Micro	4.25	3.45	2.85	2.45	2.25
Small	3.75	2.95	2.35	1.95	1.75
Medium	3.50	2.70	2.10	1.70	1.50
Large	3.25	2.45	1.85	1.45	1.25

Table 9. MRSP of FCV divided by MRSP of ICE in alternative case in alternative case.

	2010	2020	2030	2040	2050
Micro	4.25	1.85	1.61	1.43	1.39
Small	3.75	1.59	1.35	1.23	1.21
Medium	3.50	1.48	1.25	1.22	1.19
Large	3.25	1.46	1.23	1.10	1.05

Table 10. Labeled fuel economy of PV new sales in Base Case (ICE, L/100 km).

Year	2010	2020	2030	2040	2050
Micro	5.5	4.5	4	3.8	3.8
Small	7	5.8	5	4.8	4.7
Medium	9	8	7	6.5	6.3
Large	12	10.5	9.5	9	8.8

Table 11. Labelled fuel economy of PV new sales in Alternative Case (ICE, L/100 km).

Year	2010	2020	2030	2040	2050
Micro	5.5	4.5	3.5	3.5	3.5
Small	7	5.75	4.5	4.5	4.5
Medium	9	8	7	6	6
Large	12	10.5	9.5	9	8.5

average of fuel economy of four segments. The fleet average on road is calculated by multiplying fleet average labeled and deterioration factor (1.15). Fleet average of all vehicles (on road) is calculated from new sales, according to vehicle surviving curve.

3.3.2. Energy Efficiency of New Energy Vehicle

For EV and FCV, the relative ratios of energy efficiency to the baseline car are roughly 250% ~ 350% and 200% ~ 250%, respectively. For the specific electricity and hydrogen consumption rate of EV and FCV, the data are showed by sub-segments in **Tables 12** and **13**, respectively.

3.4. Key Data for Energy Unit Cost

3.4.1. Crude oil Price Assumption

The unit cost of all kinds of energy is interlinked to the future projection of international crude oil price. Two cases are set up for the energy price in future, as **Table 14** shows: in Base case, crude oil price keeps rising up before 2050, due to no effective substitutes of automotive fuels. While in alternative case, crude oil price rises before 2030, and then keeps stable afterwards, because there are no obvious substitutes before 2030, but massive replacement afterwards with the rapid development of alternative fuels and new vehicle powertrain techniques, which reduces the demand of auto oil and then mitigates the tight supply of oil.

3.4.2. Gasoline and Diesel

According to the market survey of CAERC on the energy cost for vehicle user, the gasoline cost is about 6.4 RMB per litre in 2010 and will be 12 RMB (in the constant price of 2010) in 2050 in base case, while 10.4 RMB in 2050 in alternative case, as **Table 15** shows. The situation of diesel is showed in **Table 16**. About the fuel tax, currently, fuel tax in China is the consumption tax of product oil. Since Jan 2009, fuel tax was enhanced to product oil. Fuel tax of gasoline is 1 RMB/L and that of diesel is 0.8 RMB/L. Here it assumes the tax portion to all fuels keep constant in the future.

Due to the complex situation that energy unit cost is influenced by many stages covering resource extraction, transportation, fuel conversion and distribution (the cost related to charging infrastructure for EV and hydrogen re-fuelling for FCV), our analysis is taken kindly.

3.4.3. Electricity and Hydrogen

As **Tables 17** and **18** show, for the delivered electricity and hydrogen for user, the prices which have covered the distribution infrastructure construction and operation cost

Tabel 12. Electricity consumption of EV PV (kWh/100km).

	2010	2020	2030	2040	2050
Micro	12	11	11	10.5	10
Small	16	15	14	13.5	13
Medium	20	18	16	15.5	15
Large	24	22	20	19	18

Table 13. Hydrogen consumption of FCV PV (kg/100km).

	2010	2020	2030	2040	2050
Micro	0.8	0.76	0.72	0.68	0.64
Small	0.9	0.855	0.81	0.765	0.72
Medium	1	0.95	0.9	0.85	0.8
Large	1.5	1.35	1.25	1.2	1.15

Table 14. Crude oil price assumption ($/bbl, constant prices of 2010).

	2010	2020	2030	2040	2050
Base Case	80	105	130	140	150
Alternative Case	80	105	130	130	130

Table 15. Gasoline pump price (RMB/L gasoline equivalent, constant prices of 2010).

	2010	2020	2030	2040	2050
Base Case	6.4	8.5	10.4	11.2	12
Alternative Case	6.4	8.5	10.4	10.4	10.4

Table 16. Diesel pump price (RMB/L diesel equivalent, constant prices of 2010).

	2010	2020	2030	2040	2050
Base Case	7.1	9.4	11.5	12.4	13.3
Alternative Case	7.1	9.4	11.5	11.5	11.5

Table 17. Eelectricity retail price (RMB/kWh, constant prices of 2010).

	2010	2020	2030	2040	2050
Base Case	2.6	2.4	2.3	2.1	1.9
Alternative Case	2.6	2.2	1.9	1.5	1.1

Table 18. Hydrogen retail price (RMB/kg, constant prices of 2010).

	2010	2020	2030	2040	2050
Base Case	45	57	66	78	90
Alternative Case	45	57	35	28.5	22

is 2.6 and 1.9 RMB per kWh of electricity in 2010 and 2050 respectively in base case, and 45 and 90 RMB per kg of hydrogen in 2010 and 2050 respectively in base case. The situations for both the electricity and hydrogen are different in alternative case.

Here we assume that in 2010 electricity charge station infrastructure construction and operation cost is nearly equal to the net electricity price to general user but in 2050 this ratio will change to about 0.5.

3.5 Key Data for NEC

Based on CAERC's research [4,8], for gasoline car the total non-energy cost is half of MSRP during the whole life time (NEC = MSRP * 50%), similar to the current situation in US. But for EV, the total lifetime NEC is roughly equal to the MSRP in 2010 and the situation will be similar to that of gasoline car.

Some details are following: For gasoline vehicle, during buying stage (NEC = MSRP * 10%, including buying tax/VAT tax/registration/first time check fee); during driving stage (NEC = MSRP * 40%). NEC of EV is heavily depended on the life and replacing cost of battery. Here we can only get the expert opinion due to the lack of such kind of official or published data. For EV, due to battery replacement once for life time, the situation is varied from that of gasoline vehicle in 2010; but with the technology improvement to 2020, especial with the longer battery life which can be as long as the vehicle, its total non-energy cost will be half of MSRP just as gasoline vehicle.

For FCV, the total non-energy cost is half of MSRP during the whole life time (NEC = MSRP * 50%).

4. Scenario Design and Results

4.1. Scenario Design

This section presents three scenarios for the future development of China's new energy vehicle technology: a Reference Scenario; a scenario for developing electric vehicles (EV); and a scenario for developing fuel-cell vehicles (FCV).

As **Table 19** shows, each scenario has the assumptions combined for fuel economy of conventional vehicle, additional cost for new energy vehicle and energy unit price.

4.2. Results for Reference Scenario

4.2.1. EV Development

Under the Reference Scenario, the cost of the battery, motor, and electronic control of pure electric vehicle undergoes only a slow reduction. A comparison of the integrated costs of electric passenger vehicles and petroleum-based passenger vehicles is presented in **Figure 1**.

Table 19. the assumptions for China's new energy vehicle technology development scenario.

	Reference Scenario	EV Scenario	FCV Scenario
Fuel economy of PV	Base case	Alternative case	Base case
MRSP difference between EV without battery system and ICE	Base case	Alternative case	Base case
Cost of EV battery system	Base case	Alternative case	Base case
MRSP difference between FCV and ICE	Base case	Base case	Alternative case
Retail price of gasoline, diesel, electricity, hydrogen and other alternative fuels	Base case	Alternative case	Alternative case

Basically, Micro electric passenger vehicles cannot compete with petroleum-based passenger vehicles before 2040. Since pure electric mode vehicles will be unable to match the driving range of medium-sized and large passenger vehicles, plug-in hybrid electric vehicles (PHEV) and extended-range electric vehicles (EREV) will have to be employed. However, their integrated costs will still be higher than those of petroleum-based passenger vehicles.

4.2.2. Fuel-Cell Vehicles Development

Under the reference scenario, the cost of fuel-cell vehicle technologies falls slowly. The integrated cost is unable to compete with that of petroleum-based vehicles before 2050, as **Figure 2** shows.

4.3. Results for EV Development Scenario

Under the scenario of developing electric vehicles, the R&D, demonstration, and promotion of battery, motor and electronic control technologies of pure electric vehicles achieve major breakthroughs in the near and medium term, and it is supposed that the associated cost will quickly fall.

A comparison of the integrated cost of micro pure electric passenger vehicles and petroleum-based passenger vehicles is shown in **Figure 3**. Basically, micro electric passenger vehicles are able to compete with petroleum-based passenger vehicles in around 2025; micro electric passenger vehicles then go into a phase of rapid development as small pure electric passenger vehicles. For medium-size and large passenger vehicles, PHEVs and EREVs should be used, and their integrated cost can equal that of petroleum-based passenger vehicles by 2025; they will then go into a phase of rapid development.

The EV PV penetration of new sales by sub-segments in EV Scenario are showed in **Table 20** and **Figure 4**.

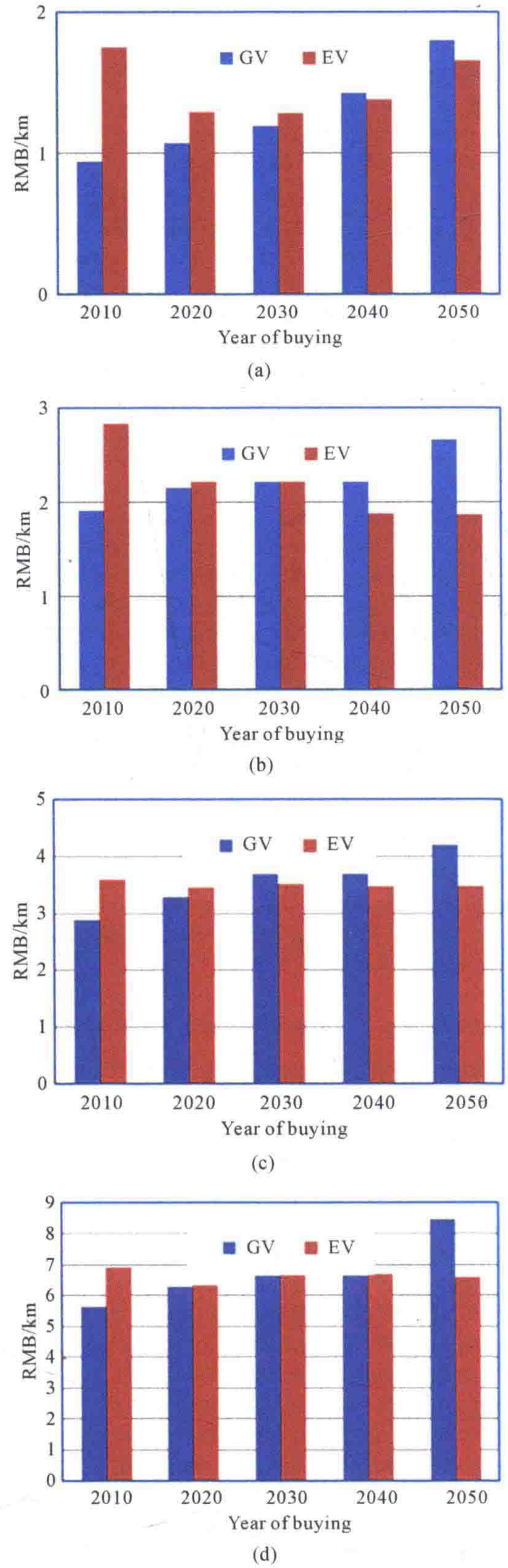

Figure 1. integrated costs of gasoline passenger vehicles and EV under the reference scenario. (a) Micro-sized; (b) Small sized; (c) Medium sized; (d) Large sized.

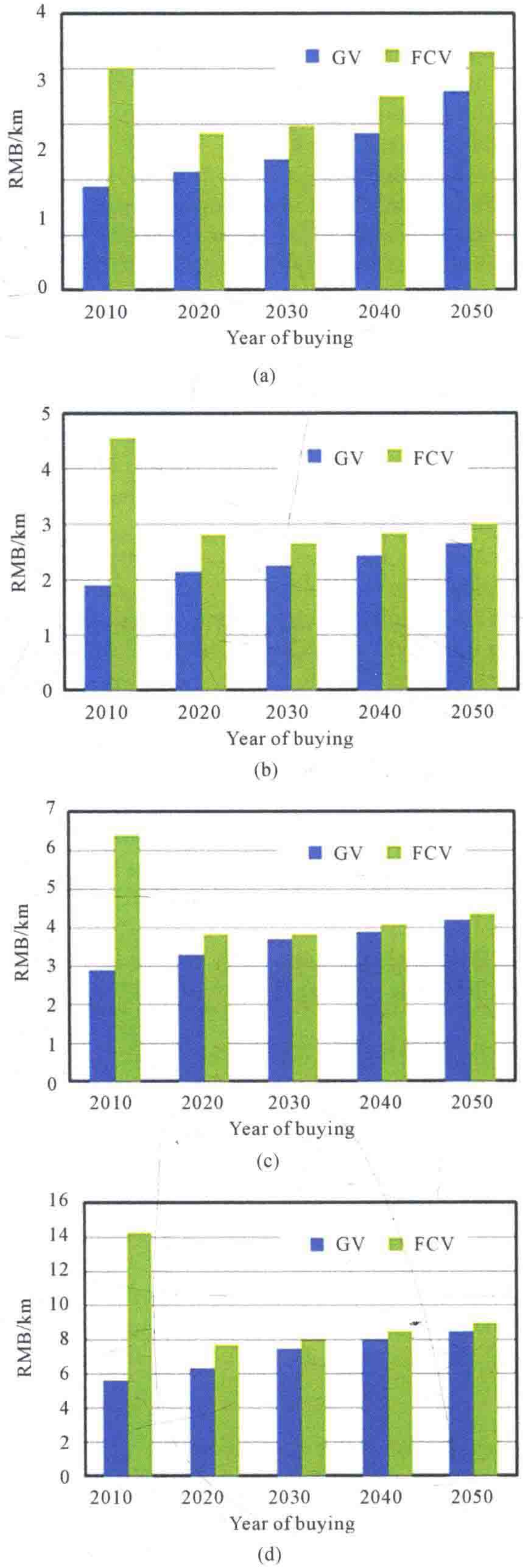

Figure 2. LCC for GV and FCV passenger cars under the reference scenario. (a) Micro-sized; (b) Small sized; (c) Medium sized; (d) Large sized.

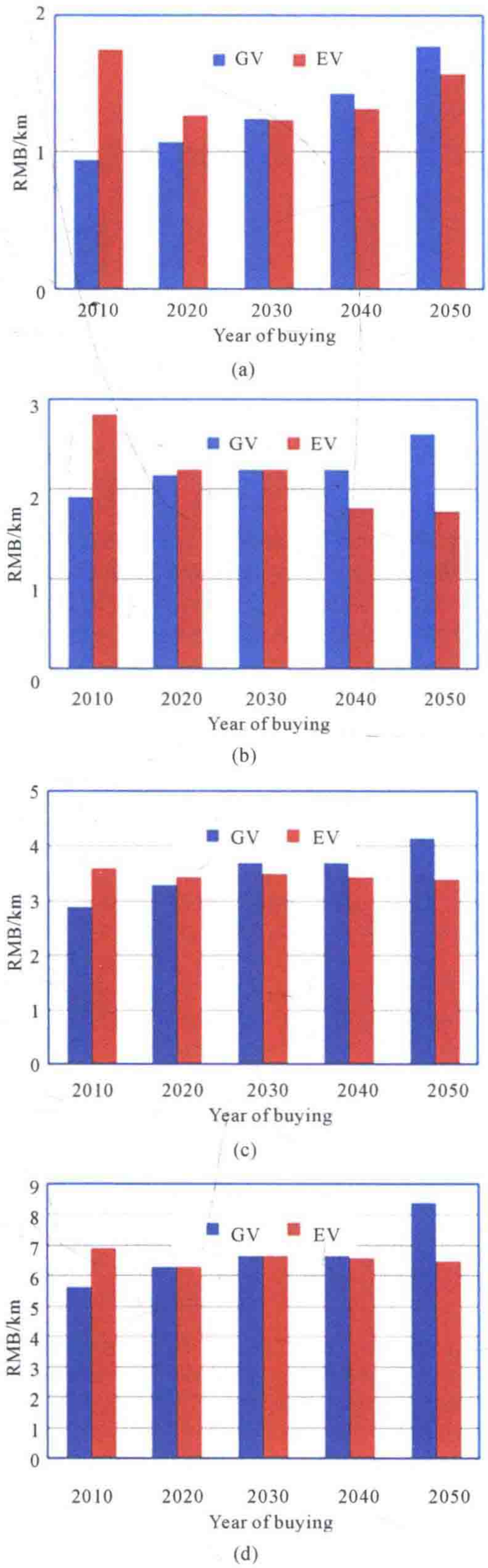

Figure 3. Comparison of the integrated cost between gasoline passenger vehicles and electric vehicles under the scenario of developing electric vehicles. (a) Micro-sized; (b) Small sized; (c) Medium sized; (d) Large sized.

4.4. Results for FCV Development Scenario

Large and medium-sized passenger vehicles are suitable for fuel-cell power. Fuel-cell passenger vehicles use hydrogen supply technology, which derives hydrogen from coal with the carbon capture and storage (CCS) technology. In the scenario of developing fuel-cell vehicles, medium-sized and large fuel-cell passenger vehicles enter a stage of rapid development in around 2035.

The trends of transport costs for large fuel-cell and petroleum-based passenger vehicles appear in **Figure 5**.

The FCV PV penetration of new sales by sub-segments in FCV Scenario is showed in **Table 21** and **Figure 6**.

5. Conclusions

Through the scenario analysis, it is found that:

1) New vehicle development needs a long time due to high initial cost for vehicle buyer in China;
2) EV will develop quickly under some conditions such as battery improvement in China;
3) FCV can develop in 20-30 years when it is needed for the environment reason in China.

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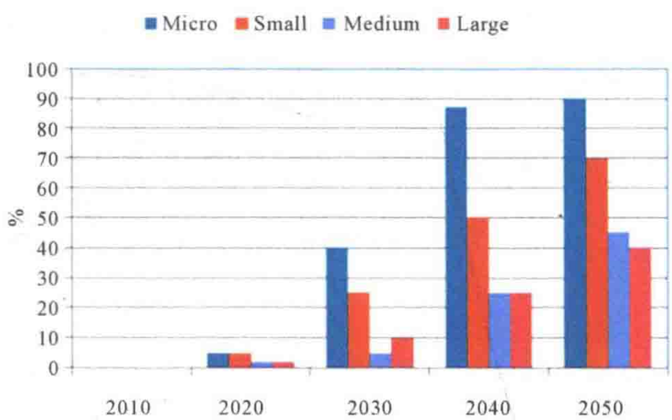

Figure 4. EV PV penetration curves of new sales in EV Scenario.

Table 21. FCV PV penetration of new sales in FCV Scenario (%).

	2010	2020	2030	2040	2050
Micro	0.0	0.0	0.0	1.0	10.0
Small	0.0	0.0	1.0	5.0	30.0
Medium	0.0	0.0	5.0	30.0	50.0
Large	0.0	0.0	10.0	30.0	50.0
Fleet average	0.0	0.0	2.0	8.8	28.0

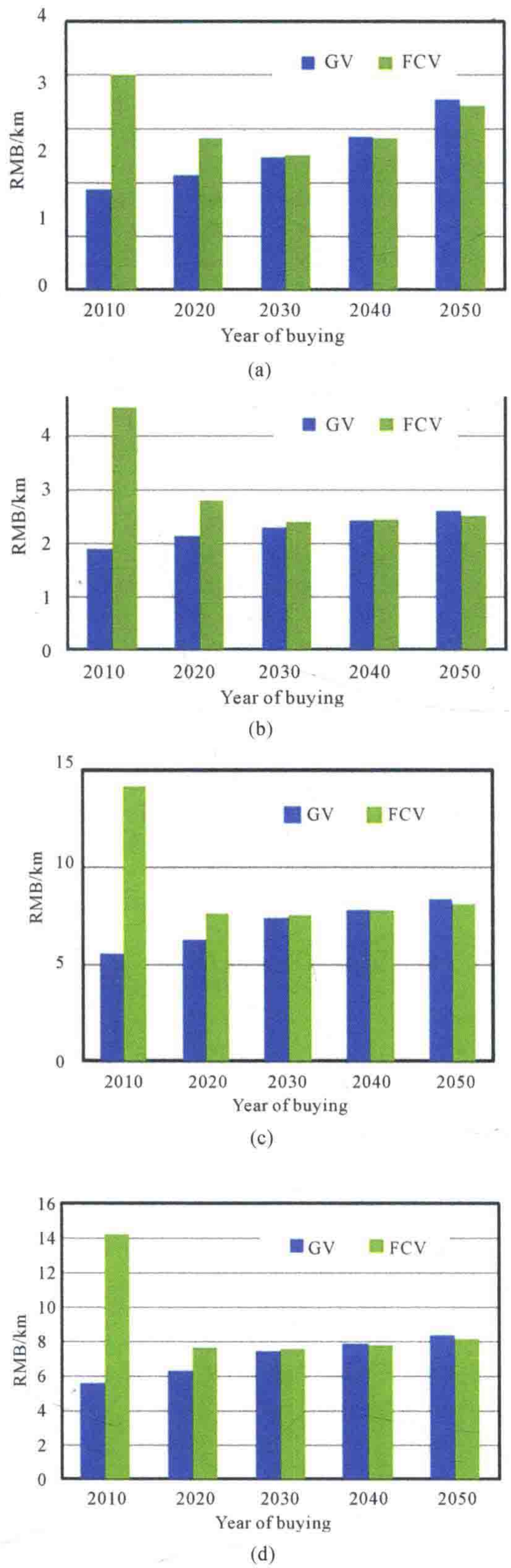

Figure 5. Transport costs of fuel-cell and petroleum-based passenger vehicles in the scenario of developing fuel-cell vehicles. (a) Micro-sized; (b) Small sized; (c) Medium sized; (d) Large sized.

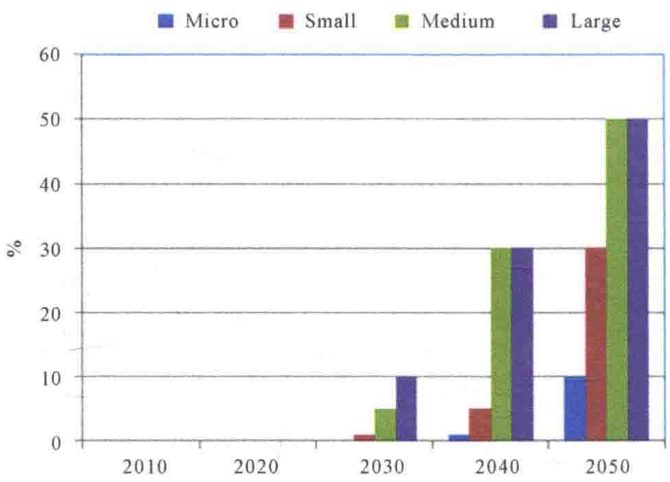

Figure 6. FCV PV penetration curves of new sales in FCV Scenario.

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2

Hybrid Vehicle (City Bus) Optimal Power Management for Fuel Economy Benchmarking

Boukehili Adel, Youtong Zhang, Chengqun Ni, Jutang Wei

Low Emission Vehicle Research Laboratory, Beijing Institute of Technology, Beijing, China.

ABSTRACT

In this paper a global optimization method (dynamic programming) is used to find the optimal power management in hybrid electric city bus for the objective to reduce the fuel consumption. Knowing that when using a global optimization method the results cannot be used in real-time control; because we need to know the entire vehicle speed in advance to perform the optimization, but in spite of that this method is very useful to make a benchmark for hybrid electric city buses fuel economy and to judge the effectiveness and improve real-time control strategies. Finally results of optimal power management are shown and discussed.

Keywords: Hybrid Vehicle; Power Management; Fuel Economy; Optimization; Dynamic Programming

1. Introduction

The study of ground vehicles has taken a tremendous interest in recent years due to the increased price of fuel and emission stringent laws. In this way, Hybrid Electric Vehicles (HEV) seems to be the most promising short-term solution and is under enthusiastic development by many automotive companies. An HEV adds an electric motor to the conventional powertrain, which helps to improve fuel economy by engine downsizing, load leveling, and regenerative braking. A downsized engine has better fuel efficiency and smaller heat loss. The reduced engine power is compensated by the electric motor. Load leveling can be achieved by adding the electric motor, which enables the engine to operate more efficiently, independent from the road load. Regenerative braking allows the electric machine to capture part of the vehicle kinetic energy.

Power management strategies for parallel HEVs can be classified into three categories. The first type uses heuristic control techniques such as control rules [1], fuzzy logic [2,3] or neural networks [4] for estimation and control algorithm development. The second approach is based on static optimization methods [5-7]. Generally, electric power is translated into an equivalent amount of fuel rate in order to calculate the overall fuel cost. The optimization scheme and figures out the proper split between the two energy sources using steady-state efficiency maps. The third type of HEV control algrithms considers the dynamic nature of the system when performing the optimization [8,9]. Furthermore, the optimization is with respect to a time horizon, rather than for an instant in time. In general, power split algorithms resulting from dynamic optimization approaches are more accurate, but are computationally more intensive.

In this paper we use the dynamic programming method to solve the problem of optimal power management in a HEV, for that reason the reference speed should be known in advance to solve the problem; thus we use a simple reference speed (not a normalized drive cycle), this reference speed contains linear acceleration and deceleration and constant speed in order to facilitate the interpretation.

2. System Specification

2.1. System Structure and Modeling

The hybrid vehicle structure is a parallel single shaft topology, which utilizes a PMSM motor placed before the transmission and coupled with the diesel engine via clutch. The engine, motor and battery are modeled using experimental data (efficiency maps for engine and motor) and an equivalent electric circuit for the battery with experimental data.

2.2. Problem Formulation

In this paper we seek to find the optimal power split between engine and electric motor in HEV in order to achieve minimum fuel consumption, this is a problem of optimal control; for that reason we need to define the criterion of optimization the constraints and the state equa-