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Analysis of the Environmental and Socio-economic Benefits of Introducing Cleaner Vehicles in China: Policy Implications

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Abstract

Along with its impressive economic growth China has experienced not only serious environmental pollution but also a very rapid increase in Green House Gas emissions and is now the largest emitter of CO_2. Together with the power and steel sectors the transportation sector is the main contributor to CO_2 emissions. In addition the transportation sector is also associated with air pollution and health damage. In order to address these challenges, at the COP15, the Chinese government set the target to decrease its CO_2 emission per GDP by 40%-45% by 2020 compared with 2005 levels and increase non-fossil fuels rate at primary energy sector of 15%. The government has also put especial efforts to reduce air pollution through the Five Year Plans by introducing targets to reduce SO_2, NO_x, PM, among others. In order to determine the feasibility to reduce GHG emissions this research evaluates the potential of environmentally friendly motorized road vehicles (Hybrid Vehicle and Electric Vehicle). The research proposed 4 scenarios and designed social-economic model & environment model & automotive model based on Input-Out analysis. The results show that HV could be the most suitable option for promoting both GHG reduction and GDP increase with 1% GDP per GHG Emission (GpE) increase under 0.23 ton /Yuan carbon tax rate in China in the short term. The results of the study also show that these options should be followed by a transition to introduce EV in the long term.

Keywords: static simulation, sustainable development policy, input-output model, hybrid vehicle, electric vehicle, carbon tax, subsidy

1. Introduction

1.1 Background

As a pillar industry in China, the vehicle manufacturing industry has developed rapidly in recent years. In 2009 China overtook USA in the number of vehicles sold (Global Note, 2014) and both production and consumption have kept a steady increase since (CAAM, 2013). Therefore, vehicle stock in china has increased very fast with an average increasing rate of 12.6% from 2000 until now, and reached 119.83milliom (China Vehicle Emission Control Annual Report, 2013) as of 2012. As estimated by Ministry of Industry and Information Technology of China, the number of vehicles will reach over 200 million units by 2020 (The Central People's Government of the People's Republic of China, 2012). As expected the rapid increase in the number of vehicles has been accompanied by increase in GHG and air pollution emissions (Andrew et al., 2013, David et al., 2014). The GHG discharged by vehicles accounts for 8% of total GHG emission in China, and it will increase to 13% by 2020 (IPCC, 2007). On the other hand, vehicle amount per household was 0.234 (based on China statistical yearbook 2011, CAAM, 2013) in 2010. This value is still very low compared to developed countries like Japan that has 1.156 (base on Japan statistical yearbook 2011, JAMA 2014). Moreover, it is expected that sales of private vehicles will reach 23–34 million and 29–42 million by 2050 under the low and high growth scenarios, respectively and the stock of private vehicles will gradually increase to 490–580 million by 2050, and will exceed the U.S. level by 2022–2024 (EIA, 2010; H.Huo *et al.*, 2012.) Consequently, GHG and air pollution emissions from vehicles will likely continue increasing in the future.

1.2 Literature Review

There are various studies that have addressed the impact of the transportation sector not only on the Chinese economy but also on the environment especially related to GHG and air pollution. Most of these studies focus on the potential shifts between private and public transportation as well as the promotion of more efficient vehicles. Yan and Crookes (2010) analyzed the future trends of energy demand and emissions associated with road vehicles in China and found that the country needs to introduce more comprehensive and effective measures such as fuel economy regulations, emissions control and promotion of more fuel efficient or alternative vehicles. Wang et al. (2011) analyzed China's vehicle amount linked to forecasts of GDP growth and found that China's vehicle amount would increase 13–17% per year. Liu et al. (2013) created and evaluated Chinese transport system and found that 13% of the energy saving and 12% of the CO_2 emission reduction will be achieved by the accomplishment of the EV strategy under a long-term objective. Ou et al. (2010) analyzed the potential of alternative vehicles and fossil fuels in the future and found that 15.8% and 27.6% reduction can be achieved in terms of life-cycle fossil energy demand and life-cycle GHG emissions respectively compare with 2007 level in the case of EV&HV introduction and decrease in fossil fuel consumption.

However, to the best of our knowledge, there is no study that tries to find potential comprehensive socio-economic and environment implications of introducing environmentally friendly vehicles in China. In this paper we make a comprehensive analysis of the promotion of such vehicles by introducing specific policy measures that consider socio-economic and environmental factors. The rest of the paper is organized as follows: Chapter 2 introduces the research Models and specific equations. This chapter also includes social-economic model under industries classification, GHG emission model and vehicle model; Chapter 3 shows a detailed simulation results analysis. Indicators like GDP, GHG, carbon tax rate, vehicle amount are analyzed also. Chapter 4 addresses final conclusion based on detailed analysis.

1.3 Research Objective

Three sub-models were constructed in this research to analyze a comprehensive balance of GDP growth and reduction of GHG emissions. Effects of carbon tax and subsidy for promotion of EV & HV were analyzed based on simulation results with the expanded I-O model. The study designed 4 scenario cases and the best carbon tax rate was estimated for each case.

A comprehensive software to solve linear, nonlinear optimization models named LINGO by LINDO SYSTEM INC. was used in this research to calculate policy introduction effects of different cases when social-economic model, GHG emission model and automotive model were constructed.

2. Method

This model consisted of three sub-models: social-economic model, GHG emission model, and automotive model. The social-economic model is based on Input-Output analysis and tries to identify the actual intermediate relationships and producing technologies between industrial sectors in order to predict the effect from indicators in each case correctly. In social-economic model, 20 industries were re-constructed from 65 based on 2010 I-O table of China and classified into 5 big sectors—normal industry, petroleum products industry, vehicle manufacture industry, energy industry and transportation industry (See Table 1& Figure.1). GHG emission model was constructed to show GHG emission amount and their emission discharge by sector and calculate the GHG decreasing effects of different industries when policy is introduced. Automotive model is a prediction model to estimate vehicle amount variation in every case. These three sub-models are interrelated. As we know, there is usually a trade-off between economic growth and the state of the environment. Likewise, environment friendly vehicle will be an indicator to affect GHG and economy. Moreover, comparatively the more EV or HV, the better the environment. The promotion of more environment friendly vehicle manufacture industry will induce economic growth. Consequently, to a certain extent, through carbon tax and subsidy policy in model, HV&EV amount can be increased, so that new industry can be promoted, while environment can be improved at the same time.

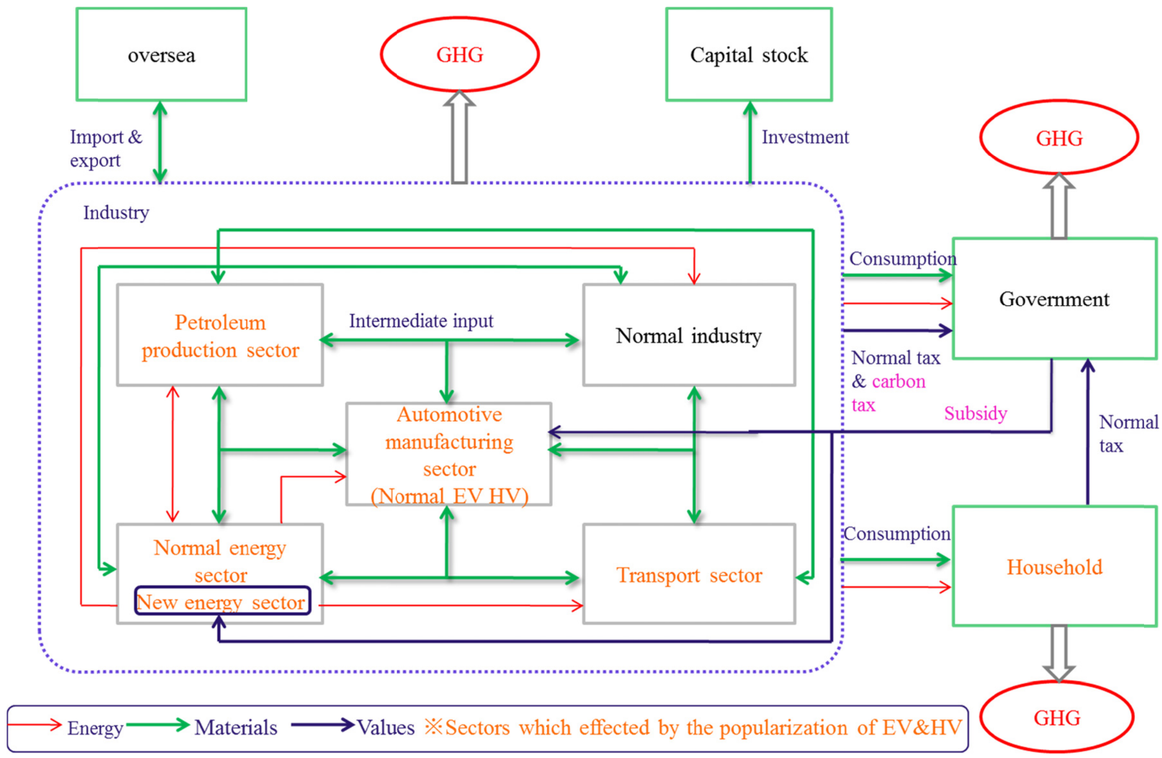

Figure 1. Model framework

Table 1. Industry classification

Industry Classification	Code of line i	Code of column j	Sector
	1	1	Agriculture, Forestry, and Fishery
	2	2	Mining
	3	3	Manufacture
Normal industry	4	4	Construction
	5	5	Gas and waste supply& treatment
	6	6	Financing, Insurance and service
	7	7	Communication and Broadcasting
	8	8	Service & others
	/	9	Petroleum products industry
Petroleum products industry	9	/	Gasoline
	10	/	Diesel
	11	/	Other petroleum products
	12	10	Normal vehicle manufacture industry
Vehicle manufacture industry	13	11	HV manufacture industry
	14	12	EV manufacture industry
	15	/	Electricity
Energy industry (Electricity)	/	13	Thermal power
	/	14	Nuclear power
	/	15	Hydro and others
	16	16	Road transportation
	17	17	Railway transportation
Transportation industry	18	18	Private transportation
	19	19	Water transportation
	20	20	Air transportation

2.1 Objective Function

The objective of this model is to maximize GDP under the environmental constraint. GDP is calculated from depreciation, income and direct tax.

En means Endogenous—volumes calculated by computer—here. *Ex* means Exogenous—volumes set already—here.

$$Maximum \;\; GDP = \sum (D + Y + \tau X) \tag{1}$$

D: Depreciation of each industry *(En vectors)*

Y: Income of each industry *(En vectors)*

X: Production of each industry *(En vectors)*

τ: Indirect tax rate of each industry *(Ex vectors)*

2.2 Material Balance

Equation 2 is the material balance and shows relationship between supply and demand based on I-O supply & demand model. Supply and demand are closed to reality. Left indicator which means supply (of sector i) is not less than right indicators which consisted of intermediate output, household consumption, government consumption, investment and net export. EV infrastructure construction investments are available under case 2 and case 3.

Unit here is million Yuan in monetary term.

$$X_i \geq \sum A_{ij} X_j + C_i + G_i + I_i + E_i - M_i + If_i \tag{2}$$

A_{ij}: Input coefficients of goods i to each industry in sector j *(Ex matrices)*

C_i: Private consumption of goods i *(En vectors)*

G_i: Governmental consumption of goods i *(En vectors)*

E_i: Export of goods i *(En vectors)*

M_i: Import of goods i *(En vectors)*

If_i: EV infrastructure construction investment from i sector *(En vectors)*

2.3 Value Balance

Equation 3 is value balance and shows the relationship between income and cost based on I-O value model. Income and cost are closed to reality. Left indicators which consisted of production income and subsidy income are not less than right indicators which consisted of intermediate input, depreciation, household income, direct tax, indirect tax and carbon tax. Subsidy to different sectors will be changed in different cases.

In this model, social cost which caused by GHG emission can be removed to internal one via pigou tax-subsidy policy, which is adopted as carbon tax-subsidy policy in this research to internalize the GHG impact and to promote new industries.

$$P_j X_j + \tau_j^S \leq \sum P_j A_{ij} X_j + D_j + Y_j + \tau_j X_j + E_{cj} \tau_c X_j \tag{3}$$

P_j: Price rate of each industry in sector i *(En vectors)*

τ_j: Indirect tax of each industry in sector i *(Ex vectors)*

τ_c: Carbon emission tax rate *(En vectors)*

$\tau^S{}_j$: Subsidy to i sector *(En vectors)*

E_{cj}: CO_2 emission coefficient of sector i *(Ex vectors)*

2.4 GHG Model

2.4.1 GHG Emission from Vehicles

GHG from vehicle and its manufacture industry are calculated in this research with Life-Cycle view. Emission at driving stage are calculated at equation 4 and all emission from vehicle-related industries are calculated at equation 5. GHG emission of vehicle at driving stage are depend on the emission coefficient of different flue type, average driving distance of different type of vehicles, average driving distance and vehicle amount.

$$W_v = \sum_{z=1}^{4} \mu_z U_z^{-1} L_z O_z \tag{4}$$

μ_z: GHG emission coefficient of z (fuel) *(Ex scalar)*

U_z^{-1}: Flue consumption rate of z *(Ex scalar)*

L_z: Yearly distance of z *(En vectors)*

O_z: Vehicle amount of z *(En vectors)*

z from 1 to 4 here:

1: Gasoline automotive 2: Diesel automotive 3: HV 4: EV

2.4.2 Total GHG Emission

The total GHG emission in China are calculated based on the production except vehicle emission.

$$W_c = \sum E_{cj} X_j + W_v \tag{5}$$

2.5 Energy Balance

Energy balance here shows the energy support at left side must be no less than energy consumption at right side of the equation. Energy is consumed by industries, household, government, net export and additional EV consumption.

$$bX_e \geq \sum B_i X_i + B_c C_e + B_g G_e + B_E E_e - B_M M_e + D_e \tag{6}$$

b: Energy production rate *(Ex vectors)*

X_e: Production of normal energy and clean energy sectors *(En vectors)*

B_i: Energy consumption rate of production in sector i *(Ex matrices)*

C_e: Energy consumption rate of household sector *(En vectors)*

G_e: Energy consumption rate of government *(En vectors)*

E_e: Energy export *(En vectors)*

M_e: Energy import *(En vectors)*

D_e: Energy demand of EV *(En scalar)*

REV is estimated base on yearly distance of normal vehicle. It is supposed that EV replaced normal vehicle and be treated no different from it. The energy consumption rate of EV is set as BYD E6—the most well-known EV in china currently. So the REV is calculated as 1369 kWh/year with the data provided by BYD automotive homepage.

$$D_e = REV * O_4 \tag{7}$$

REV: Yearly energy consumption of EV *(Ex scalar)*

2.6 Vehicle Model

2.6.1 Vehicle amount

Since this is a static analysis, the study period is 1 year, so the vehicle increasing model is simply decided by the average vehicle increasing rate as 12.6% which was mentioned in Chapter 1.

To EV demand, we assumed a HV/EV ratio of 3 based on the Japanese current situation (eco-car policy).

$$\sum_{z=1}^{4} O_z = \sum_{z=1}^{4} Oc_z * (1 + IO) \tag{8}$$

$$\tau_{a3}^{S} IHV = O_3 - Oc_3 \tag{9}$$

$$\tau_{a4}^{S} IEV = O_4 - Oc_4 \tag{10}$$

$$O_3 - Oc_3 \leq 3(O_4 - Oc_4) \tag{11}$$

z from 1 to 4 here:

1: Gasoline automotive 2: Diesel automotive 3: HV 4: EV

Oc_z: current vehicle amount if z *(Ex scalar)*

IO: average increase rate of vehicle *(Ex scalar)*

τ^S_{a3}: subsidy to HV manufactory industry *(En scalar)*

τ^S_{a4}: subsidy to EV manufactory industry *(En scalar)*

IHV: HV increase rate based on subsidy *(Ex scalar)*

IEV: EV increase rate based on subsidy *(Ex scalar)*

2.6.2 Infrastructure of EV

It is clear that EV infrastructure must be constructed when EV is introduced. Consequently, EV infrastructure is treated as a part of EV produced by EV manufacture industry finally.

$$If = Iv * O_4 \tag{12}$$

$$If_i = r_i * If \tag{13}$$

If: Total EV infrastructure construction investment *(En scalar)*

Iv: EV infrastructure investment volume when 1 EV is introduced *(Ex scalar)*

r_i: EV infrastructure rate of i sector *(Ex vectors)*

2.7 Finance Budget Model

2.7.1 Government Budget Balance

Equation 14 is set for budget security to make government incomes at left side equal to government expenditures at right side. All government incomes are supposed to pay for policy making in this model, and no more additional payment at the same time.

Government incomes consist of direct tax, indirect tax and carbon tax. Government expenditures are consisted of government payment, government saving and subsidy.

$$\tau^d \sum Y_i + \sum \tau_i X_i + \tau_c W_c = \sum G_g + S^g + \tau_i^S \tag{14}$$

τ^d: Direct tax rate *(Ex scalar)*

G_g: Government consumption *(En vectors)*

S^g: Government saving *(En scalar)*

2.7.2 Household Budget Balance

Equation 15 is constraint to avoid abnormal results with extreme income.

Total income is separated by direct tax and disposable income (Equation 16). And household saving and household consumption consisted disposable income (Equation 17).

Equation 18 and 19 show the contribution of household consumption.

$$Y_i \geq V_i X_i \tag{15}$$

$$Y_k = (1 - \tau^d) \sum Y_i \tag{16}$$

$$S^p = \beta Y_k \tag{17}$$

$$P_i C_i = (1 - \beta) Y_k \alpha_i \tag{18}$$

$$\sum \alpha_i = 1 \tag{19}$$

V_i: Income rate of sector i *(Ex vectors)*

Y_k: Disposable income *(En scalar)*

S^p: Household saving *(En scalar)*

β: Saving rate *(En scalar)*

2.7.3 Investment & Saving Balance

Either government saving or household saving are treated as investment in this static model.

Investment is consisted of net investment and net export.

$$S^p + S^g = \sum (I_j + (E_i - M_i)) \tag{20}$$

$$I_n = f_n * \sum (I_j + E - M) \tag{21}$$

I_j: Net investment *(En scalar)*

f_n: Contribution rate of investment *(Ex vectors)*

2.7.4 Carbon Tax Balance

Carbon tax is introduced in every industry and base on their CO_2 emission.

All carbon tax collected must be paid as subsidy.

$$\tau_c W_c \geq \tau_e^S + \tau_a^S \tag{22}$$

$$\tau_c W_c = \tau_c E_{cn} X_n + \tau_c E_{cp} X_p + \tau_c E_{ce} X_e + \tau_c W_v \tag{23}$$

τ^S_e: Subsidy to clean Energy Sector *(En vectors)*

τ^S_a: Subsidy to Automotive manufacture sector *(En vectors)*

2.8 GHG emission model (Environmental constraint)

We identified the optimal policy based on simulation results. To calculate the most optimal carbon tax rate and the best case, a sub-case indicator, which is called GDP per Emission (GpE), was introduced.

CO_2 emission constraint is set to increase GDP quality, more CO_2 is acceptable but much more GDP is required—much more GDP per CO_2 emission.

$$GpE = GDP / GHG \tag{24}$$

$$GpE \geq (1 + r)GpE' \tag{25}$$

r: decrease rate of GpE *(operation variable)*

GpE': GpE value in Base case *(En scalar)*

2.9 Case Setting

We proposed 4 cases as shown in table 2. Case 0 is the baseline case and assumes 2010 data with no policy introduction. In case 1, we introduce a carbon tax which revenues are used as subsidy to promote HV manufacturing sector. In case 2, we introduce a carbon tax which revenues are used as subsidy to promote HV&EV manufacturing sector and EV infrastructure construction. In case 3, we introduce a carbon tax and the revenues are used as subsidy to promote HV&EV manufacturing sector, EV infrastructure construction and clean energy (solar, wind, hydro, nuclear) sector.

"○" in table 2 means policy introduced in terms of "×" in table 2 means without policy.

Table 2. Case setting

	Carbon tax	Subsidy to HV	Subsidy to EV & infrastructure	Subsidy to Clean Energy sector
Case0	×	×	×	×
Case1	○	○	×	×
Case2	○	○	○	×
Case3	○	○	○	○

3. Results Analysis

A static analysis was used in this research so the simulation period was set only one year with base year of 2010. To estimate different policy efficiencies, 4 cases were set and been simulated. Simulation results were analyzed at different aspects in this chapter.

3.1 Total GDP&GHG Value

Horizontal axis in figure 2 shows different GpE increasing constraints compare with base level. Bar graph shows GDP volume and line graph shows GHG emission volume under different GpE constraint, respectively. Graphs stop at 6% GpE means that no feasible result can be found when GpE constraint is bigger than 6%. Case 0 is base case with no policy introduced. That's the reason why GDP decreased with the increase of GpE and got no feasible result at 6% point. Moreover, GHG and GDP went down at same time and with same intensity. It is thus clear that the only way to decrease GHG emission at case 0 is to decrease GDP. Case 1 did better than case 0 at both aspects of GHG and GDP because of the HV & subsidy policy. It could get feasible results at 6% level. HV is a good choice to create sustainable & environment friendly society after all—easy to introduce and less risk—from this figure. Case 2 got no feasible results after 4% GpE constraint because of the strong requirement of HV & EV introduction. GDP at case 2 is very interesting compare with other cases that became NO.1 at 4% point. Moreover, the stronger GpE is, the better GDP than other cases at the process from 3% to 4%. It means that carbon tax & HVEV-subsidy policy worked at the process from 3% to 4% to make GDP keep a good level than other cases—when they must sacrifice economy to fit environment targets. However, at the aspect of GHG emission level, they were at different situations. Case 2 always at the highest place when GpE moved. The reason is considered that the increasing electricity demand are fed by current power sector which occupied by thermal power especially by coal—the highest emission power generation type—in China. It makes EV in china discharge much more GHG than normal vehicles in current. Case 3 added subsidy to promote clean energy sector so that EV can be more environment friendly. It made EV introduction be sustainably and smooth under case 3. From this figure, case 3 did as well as case1 at both aspects of GHG and GDP from 1% GpE constraint to 4%, and better than case 1 at 5% in terms of GHG even they take same GDP score. So that EV industry can be activated at 5% GpE constraint is a reason be considered.

The most important result from figure.2 is that GDP & GHG are affected by environment friendly vehicles introduction but limited in whole social economy. Consequently, production must be decreased to achieve a higher environment target in this model generally.

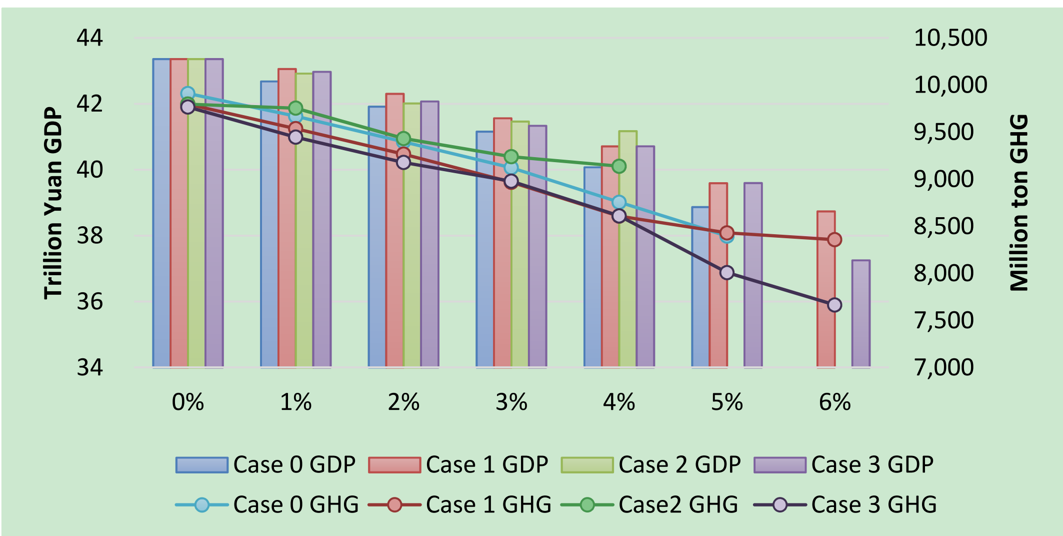

Figure 2. GDP&GHG values in difference cases

The best GpE constraint for each case cannot be taken by figure.2 only. Thus a definition of margin GDP was introduced to analyze it. Margin GDP was shown at equation 25 which means that how much GDP will be decreased when 1 ton GHG be cut off. It is clear that the less, the better.

$$Margin\ \ GDP = \Delta GDP \ / \ \Delta GHG \tag{26}$$

Case 0 in figure.3 is a stead line under every GpE. It is an evidence in support of the result concluded at figure.2

that production must be decreased to achieve a higher environment target in this model generally, therefore GDP and GHG decrease at same rate at case 0 with no policy introduced. Case 1 gave a very good score here—under base case at all. It means that HV-subsidy policy works well in model and can be a good policy in real society. The lowest margin GDP here is at 1% GpE point—is the best GpE for case 1. A big number change occurred at case 2 from 1% point. It is because of the high emission power resource are not be replaced in this case that makes EV discharged more GHG than normal vehicle. On the other hand, the more GpE constrained, the better EV industry activated, so that ΔGDP became less with GpE changed. Finally, the best GpE for case 2 is 4%. Case 3 is similar as case 1 which under case 0. It can be an evidence in support of the result that EV can be promoted sustainably when clean energy introduced. The best GpE for case 3 is 1% from figure.3.

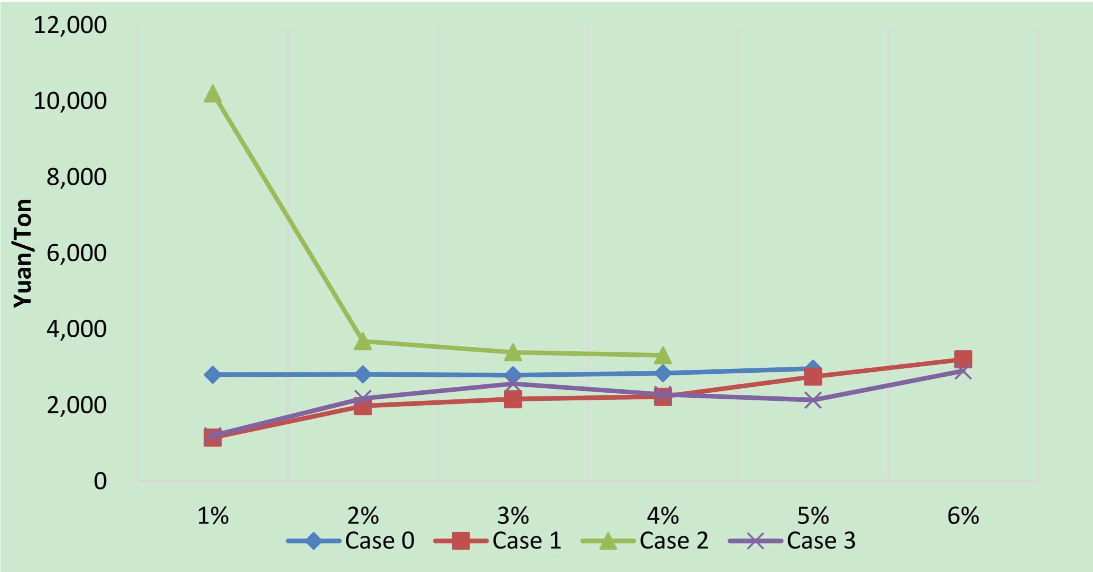

Figure 2. Margin GDP of every cases

3.2 Situations in Vehicle Sector

In this part, vehicle situation was analyzed under their best GpE point of every case. When we consider rapid developing economy of China, we can understand that it is difficult to keep GpE increasing by vehicle related industries only. We need to include all the industries. Therefore, it is meaningful at case 1 and case 3 to increase GpE even 1% only. To estimate results close to real situation, we set a scope for normal vehicle amount from -20% to 20% compared with base case. To promote EV demand, 1 EV at least must be introduced for every 3 HV—which is based on Japan Eco-car policy mentioned in chapter 2. At the same time, EV power charging infrastructures were treated as a part of EV. It is very clear from figure 4 that GHG emission cut at the lowest level of 298 million tons compared with other cases by HV-subsidy policy introduced at case 1, which means a success of this policy. The amount of HV was 16.65 million units at case 1. However, HV amount changed a little at case 2 because of the big amount investment of EV power charging infrastructures and EV of 4.09 million units, which caused a subsidy shortage. As for o GHG emissions, they were higher than case 1 due to the high reliance on coal power generation in China. This means that, under current power generation system, EV would discharge more GHG. In other words, case 3 is very necessary when we consider a sustainable development approach in China. More subsidy were paid to clean energy sector at case 3, therefore, HV & EV amount were less than case 2. On the other hand, the efforts of clean energy introduction were not shown at this figure even when compromising on EV & EV amount. The total GHG was higher than case 1 and case 2 still. In order to promote a sustainable energy sector, a carbon tax policy is not enough. Government must pay more attention and support to the sustainable innovation at energy sector. Depending on government participation the EV introduction could be an effective initiative.

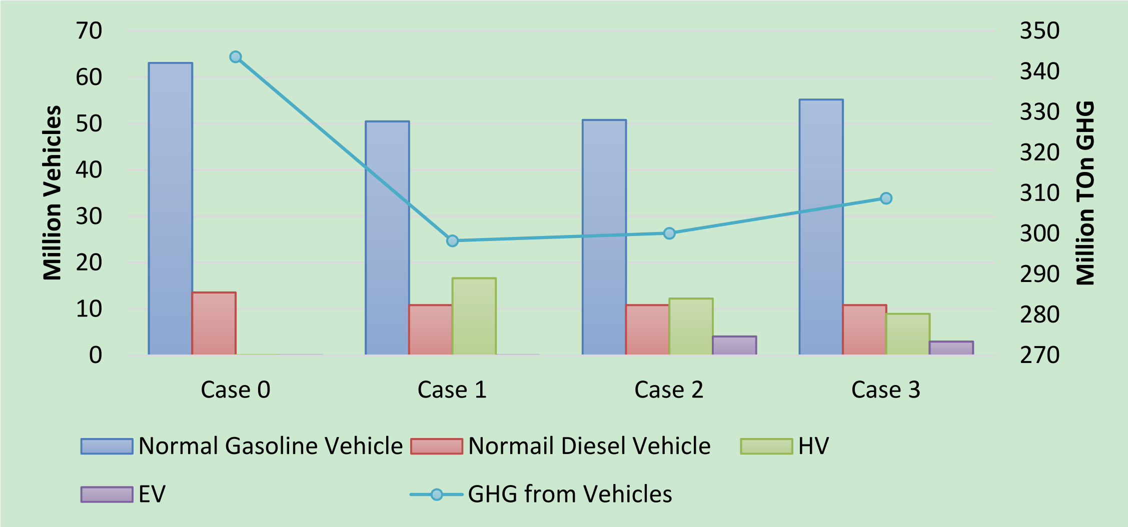

Figure 3. Vehicle amount and GHG emission from vehicles of each case

3.3 Carbon tax & Subsidy

The introduction of EV vehicles is not the only evaluation standard. A subsidy volume and its finance resource—carbon tax—must be considered at same time. In case 1, all carbon tax income was spent as subsidy to promote HV manufacture industry and to increase HV amount, the score was that 271.4 trillion Yuan subsidy was used to increase 16.65 million HV when the carbon tax rate was 0.23 Yuan/ton. It is a very low rate for industries so case 1 is a low-affection case at the aspect of social economy. Case 1 can be treated as a low-cost but high-efficient policy. Carbon tax rate increased to 11.5 Yuan/ton in case 2, an available medium level. However, the expenditure was far different from case 1. The total carbon tax income was 999.2 trillion Yuan in this case but almost 2/3 of them were used for EV & EV infrastructure. In spite of the high subsidy to EV, the EV amount was at a low level of 4.09 million units. High EV infrastructure demand was the reason considered. It was a high investment but low profit policy, and seemed an erroneous decision in economics but the only way to realize sustainable society of transportation sector. In case 3 we introduce a high carbon tax rate of 28.8 Yuan/ton. Clean energy sector cost a main part of tax income, therefore, subsidies to HV & EV was less than in case 2. It is clear from the figure.5 that big amount tax and subsidy cannot carry environment situation—although it is necessary investment to construct sustainable development society.

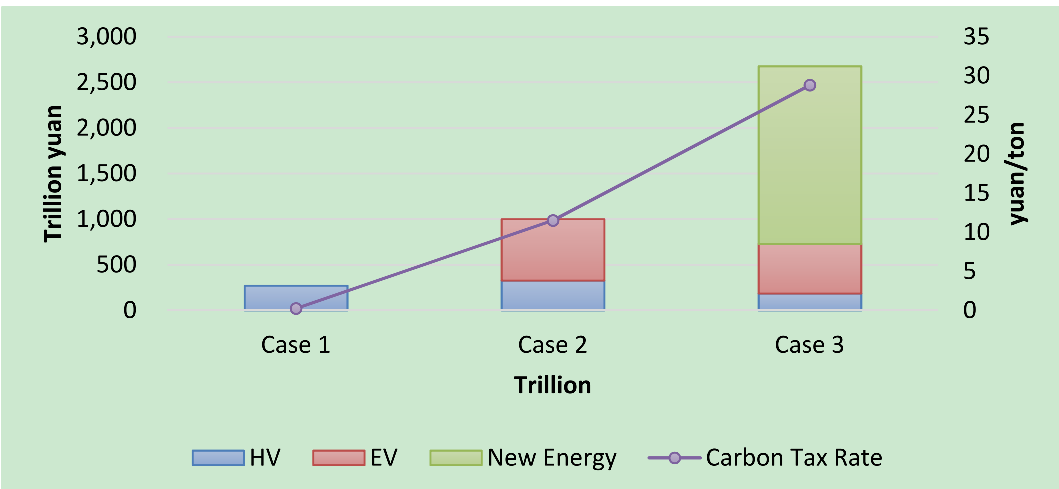

Figure 4. Carbon tax rate, subsidy amount and it's spend way

3.4 Other Indicators

Some of the detailed indicators shown in table 3 were analyzed in this part. The GpE increase rate of case 1 and case 3 were 1%, which means that 4628.8 Yuan of GDP causes 1 ton GHG emission. Case 2 did best in this aspect with 4738.8 Yuan/ton. We should pay attention that GpE is decided by 2 variable indicators, so that the increase of GpE did not equal to the GDP increasing or GHG decreasing. It shows an increase of economic quality. Case 1 and case 3 were better than case 2 at the aspect of household disposable income and household saving. To fit 4% GpE increasing, case 2 must expand domestic demand and enlarge consumption of household sector to stimulate GDP. Low household saving, however, is not a good situation of sustainable development.

Table 3. Other indicates calculated of each case

	Case 0	**Case 1**	**Case 2**	**Case 3**
GpE (Yuan/Ton)	4583	4628.8	4738.8	4628.8
Disposable Income (Trillion Yuan)	2492.292	2475.977	2368.998	2471.245
Household Saving (Trillion Yuan)	734.7729	667.4682	132.384	648.9898

4. Discussion

Based on the analysis at chapter 3 we can conclude that the best GpE for case 1 is 1% increase and the carbon tax rate is 0.23 Yuan/ton. The best GpE for case 2 is 4% increase and the carbon tax rate is 11.5 Yuan/ton. And the best GpE for case 3 is 1% increase and the carbon tax rate is 28.8 Yuan/ton. The results of the study suggests that it would be meaningless to introduce only HV EV and EV infrastructure without clean energy promotion. This is clearly shown in Case 2 where GHG emission from EV at power generation stage is higher than normal vehicle in spite of 4% GpE increase. Though the total GHG emission of case 3 is higher than case 1, GHG from vehicle is less than case 1. Because industries of case 3 are likely to decrease their production to decrease cost for high carbon tax rate, in terms of the environment friendly vehicles introduction is less than case 1. Although EV manufacture sector can be activated under 4% GpE constrain, GHG from vehicles is higher than case 3, so an integral clean energy strategy is necessary to introduce EV in China. However, HV introduction of case 1 is highly efficient after all but when we compare with HV-only policy of case 1, case 3 is more sustainable with future potential. In other words, case 3 is the best case under the premise of a long term approach. This research is a static simulation so that time is not considered. In practice every evolution in case 3 must not only consider the low efficiency but also involves a huge amount of investment and long time to be realized. For this reason HV-subsidy policy in case 1 has the best outcome in the short term.

A future work should expand this research and include a dynamic simulation that considers time indicator. Investment efficiencies from every industry, capital stock changes, environment friendly vehicles population changes and specific clean energy sector evolution can be estimated through dynamic simulation.

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Appendix

Table 4. Indirect tax rate τ_j

τ_1	0.001130269	τ_6	0.144469393	τ_{11}	0.046053995	τ_{16}	0.039553692
τ_2	0.108127664	τ_7	0.03870995	τ_{12}	0.027022838	τ_{17}	0
τ_3	0.037837167	τ_8	0.043015327	τ_{13}	0.019599121	τ_{18}	0.042906495
τ_4	0.041203021	τ_9	0.106663839	τ_{14}	0.024830775	τ_{19}	0.01726713
τ_5	0.075836312	τ_{10}	0.04319364	τ_{15}	0.015707622	τ_{20}	0.041627609

*Calculated based on I-O table 2010, China.

Table 5. Indirect tax rate V_i

V_1	0.556303287	V_6	0.144469393	V_{11}	0.046053995	V_{16}	0.039553692
V_2	0.108127664	V_7	0.03870995	V_{12}	0.027022838	V_{17}	0
V_3	0.037837167	V_8	0.043015327	V_{13}	0.019599121	V_{18}	0.042906495
V_4	0.041203021	V_9	0.106663839	V_{14}	0.024830775	V_{19}	0.01726713
V_5	0.075836312	V_{10}	0.04319364	V_{15}	0.015707622	V_{20}	0.041627609

*Calculated based on I-O table 2010, China.

Table 6. CO_2 Emission coefficient E_{cj}

E_{c1}	0.000024	E_{c6}	0.000008	E_{c11}	0.000082	E_{c16}	0.00008259
E_{c2}	0.00014	E_{c7}	0.000008	E_{c12}	0.000076	E_{c17}	0
E_{c3}	0.000077	E_{c8}	0.000008	E_{c13}	0.000986	E_{c18}	0
E_{c4}	0.000005	E_{c9}	0.000008	E_{c14}	0	E_{c19}	0.00015535
E_{c5}	0.000011	E_{c10}	0.0000699	E_{c15}	0.000127	E_{c20}	0.00017214

*SS.Wang et al., 2013.

Table 7. Other *Ex* indicators

μ_1	0.002361	U_1	12.4	Oc_1	6311.68	IHV	0.000232
μ_2	0.002778	U_2	9.9	Oc_2	1357.52	IEV	0.000086
μ_3	0.002361	U_3	30.4	Oc_3	3.9603	τ^d	0.2
μ_4	0.000717	U_4	7.6	Oc_4	1.239	Iv	9.68
b	0.961669826	IO	0.126	REV	1369.077		

* Calculated based on China automotive industry yearbook 2010.