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Dynamic Simulation Assessment of Environment Friendly Vehicles Introduction and Clean Energy Promotion Policy in China

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Abstract

A unique GHG emission decline target was released by the Chinese government to facilitate the decrease in GHG emission per unit of GDP in China. In other words, an increase in GHG is permitted under a GDP reflecting a better quality environment quality. Therefore, technology promotion and policy evolution are necessary to realize this within a limited period. This research considered a GHG emission tax and subsidy policy to achieve environmental targets via environment friendly vehicle introduction and clean energy promotion. An optimization simulation model based on extended input-output model was explored to compare with four policy scenarios. The simulation result shows that hybrid vehicle and electric vehicle introduction are powerless to meet environment targets unless more attention is paid to solar power and wind power along with thermal power. This research proposed an optimal GHG emission tax rate and subsidy rate for policy makers in China to reach their environment goal.

Keywords: input-output analysis, dynamic modeling simulation, environment friendly vehicle, GHG emission tax, subsidy, clean energy

1. Introduction

Climate change has become one of the greatest challenges of our time. Thus how to protect the Earth's climatic environment has become the most serious challenge faced by humans. With its in-depth scientific understanding, the relationship between socio-economic activities and climate change has been confirmed, namely, the emission of a large quantity of greenhouse gas (GHG) due to the socio-economic activities is an important cause of climate change (IPCC 2006). As a developing country, China is now at the stage of rapid economic development since the economic reforms of the 80's (MEPC 2012). In 2006, China surpassed the U.S. to become the world's largest GHG emitter (IEA2008). In 2010, China's total GHG emissions accounted for 26% of the total world emissions, which was far more than 17.2% (IEA 2012) of the U.S. ranked in second place. China's GHG emission issue has also become a common concern of the world's governments and academia. To deal with this situation, the Chinese government established China's GHG emission reduction target during COP15 of the UNFCCC: the GHG emissions per unit of GDP in 2020 will be reduced by 40%-45% compared to that of 2005 (CGC 2011, 2015).This research aims to propose an optimal policy to meet that environmental target through a GHG emission tax-subsidy policy introduction via hybrid vehicle (HV) and electric vehicle (EV) popularization and clean energy promotion using an optimization simulation model exploration based on an extended Input-output model(NBSC 2013).

According to the data in the IPCC report (2007), the GHG emissions from human activities were derived mainly from the energy supply (25.9%), industrial production (19.4%), agriculture, forestry and animal husbandry industry (30.9%) and the transport sectors (13.1%). The report also mentioned that the GHG emissions of China's transport sector accounted for about 8.6% of China's total emissions, and it was expected that the corresponding emissions would reach 13% of the world average in 2020 (IPCC 2007). By taking into account economic growth and the growth in total emissions of GHG in 2020, it is expected that the GHG emissions of the transport sector in China will increase rapidly (OICA 2015).

If China's per capita vehicle parc reached the current U.S. level, the total number of vehicles would be four times higher than in the U.S.(OICA 2013, UN 2011). While in smaller countries, the rapid growth of vehicles may not affect world gasoline supply and even gasoline related industry changes, countries like China will significantly affect gasoline demand. Considering that conventional vehicle exhaust contains GHG, and also carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_x) and other harmful gases, as well as particulate matter (PM), the introduction of environmentally friendly vehicles is a meaningful measure (MEPC 2011). If, for instance, consumers in China directly select environment friendly vehicles (SCC 2008, 2012) this will not only have a huge economic and environmental advantages, but will also make a significant contribution to energy-saving and sustainable development.

Consequently, this research utilizes the transport sector to discuss how to expand the vehicle parc of environment friendly vehicles especially HV and EV in the market through the introduction of policy to reduce exhaust GHG emissions from vehicles, so that the environment friendly vehicle manufacturing industry can also be developed actively. Clean energy promotion will be considered while the GHG emission by EV is affected by energy industry. Ultimately, at the same time as energy-saving and emission reduction, the economic industrial structure can also be optimized and upgraded, maximizing the overall economic benefits. This research shows its original contribution in terms of (1) detailed sector classification in the automotive manufacturing sector to analyze the sector promotion under different policies, (2) provides a new proposal for HV and EV promotion in China via GHG emission tax and subsidy policy, (3) indicates dynamic GHG emission coefficients in the energy sector when clean energy is introduced every year.

This research considers reducing GHG emissions as the environmental goal, therefore, we use internationally accepted methods, and all greenhouse effect gases will be transferred into the standard amount of carbon dioxide equivalent (CO_2-eq) based on the greenhouse effect potential of different gases when calculating the GHG, for evaluation.

2. Literature Review

As a part of a sustainable society international experts and scholars consider the use of environmentally friendly vehicles a necessity. Researchers are mainly engaged in research on: vehicle parc prediction; GHG emission and air pollution by transport sector; transport sector promotion policy; and carbon tax related research. Hao and Wang (2011a, 2011b, 2012; Wang et al. 2011) used the FEEI model combined with a logistic model to predict the total number of China's vehicles. He and Chen (2013) adopted the LEAP model, and analyzed the introductory forecast and environmental impact of HV and EV in China using LCA. In addition, it fails to calculate the relationship between the growth in vehicle numbers and the automobile industry, and there is also no concept of "optimum choice" between vehicle quantity and the environment. Ou, Zhang et al. (2012) also established a model based on LCA, and set the demand changes for China to develop alternative energy and alternative automotive energy under different scenarios and the predictive analysis of GHG emissions.

Hao, Ou et al. (2014) undertook inductive analysis of China's promotion subsidy policy for HV and EV since 2009, and calculated the current cost of using EV in China. According to conclusions, there is still some difficulty in popularizing EV in China. The research indicates that at least until 2020, it is impossible to reach a large number of EV in the Chinese market. The fact that financial resources forsubsidy policy is derived from general government revenue also indicates it is difficult for the current subsidy policy to provide long-term grants for the popularity of EV, which is also a main reason for the grant to be implemented for only four years (2009-2013). Therefore, it is necessary to have a long-term and recycled subsidy policy with adequate financial resources. Yan and Crookes (2010) reviewed China's transportation sector incorporating vehicle parc, environmental pollution and energy security, and after quoting a large number of documents and summaries, they obtained a very reliable conclusion. China's vehicle parc will continue to maintain high growth in the next 30 years, and now China is at the cross roads of affecting future vehicles in China, energy and its environment, through the improvement of existing ICEV (internal combustion engine vehicle) or the use of an alternative program (PHEV, etc.). China will grasp the priority in the face of environmental challenges, while the early action will be essential for wins.

Therefore, although there is much research in the fields of transportation, energy, economy and environment, there are few studies of environment friendly vehicles introduction policy evaluation. A sustainable policy suggestion is urgently needed for the promotion of environment friendly vehicles.

3. Methodology

The linear optimization software LINGO developed by LINDO SYSTEMS INC. is used in this research to conduct a computer simulation to calculate the operation of the preset model and seek solutions consistent with the research aims and as close to a realistic situation as possible to undertake analysis of the results. It is a dynamic model simulation of the period from 2010 to 2020.

The models in this research can be divided into three: the socio-economic model, GHG emission model and the vehicle demand model. The socio-economic model is the basic model of this study based on Input-output model, and attempts to construct a "virtual community" reflecting a real society, so that the operating results of the model will reflect reality. The GHG emission model calculates the GHG emissions due to socio-economic activities. The automotive demand model reflects the relationships between social demands for vehicles and socio-economic progress, together with environmental protection.

The theoretical framework is shown in Figure 1, where various socio-economic sectors are divided into industry, government and household. The industry produces products and energy, and pays taxes to the government; the government consumes products and energy, and regulates taxes; the citizens consume products and energy, and pay taxes to the government. Industry (see Table 1) can also be divided into normal industry (8 sectors), petroleum products industry (3 sectors), automotive manufacture industry (4 sectors), energy industry (5 sectors) and transport industry (4 sectors). The industry classification is based on an extended version of China's input-output table for 2010.

In order to conduct a comparison of the policy effect, this research simulated five cases (see Table 2): Case 0 is the basic as usual case with no policy introduced, and is the case to show the policy effects on other cases. Case 1 is to lower GHG emissions using HV only in order to see the environment and economic effect of HV introduction via GHG emission tax and subsidy; Case 2 uses HV and EV simultaneously, to show the difference in policy effect between HV and EV; Case 3 reflects the use of subsidies and development of the electricity industry while using HV and EV. Case 3 is to show the effect caused by clean energy after the introduction of HV and EV. In addition, there is a segment simulation relevant to each case to calculate the most effective scenario when using the policy. For example, different extents of environmental emission reduction targets should be designed for Case 1 and Case 2, which are used to observe a variety of HV or EV emission reduction policies in line with realistic conditions for socio-economic development, and thus to know the best effect for certain situations. For Case4, the thermal power will be reformed and evolved further from the original hypothesis to calculate the emission reduction potential of this policy.

Based on the above model, this research compares the influence of different policies through forecasting results in different scenarios. It does not consider the policy of a separate introduction of EV. The main reason is due to the non-obvious effect of directly studying the GHG emissions with respect to current EV by skipping the hybrid electric vehicles, and the required cost is far higher than the current HV with mature technology. There is still much technical improvement potential for the EV and the corresponding market development evaluation has also not been completed. Therefore, it is impossible to achieve good economic and environmental effects by introducing EV directly and skipping HV.

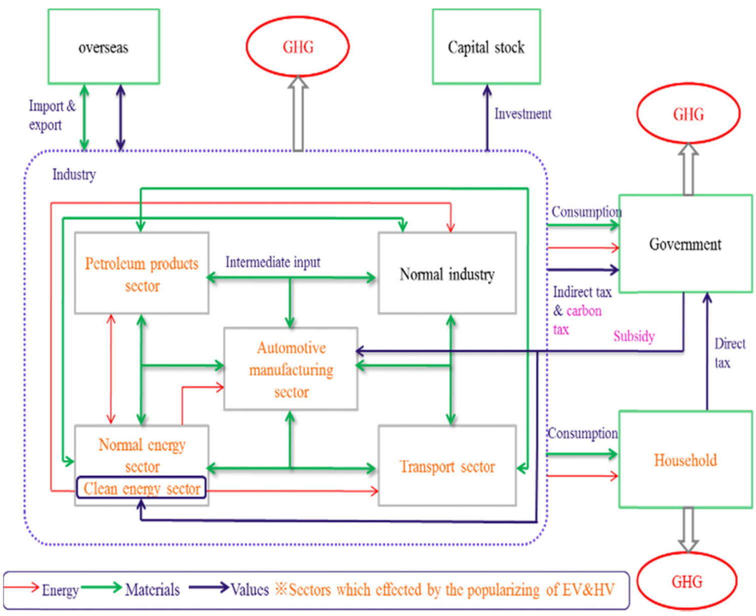

Figure 1. Research framework (K.Y. LU et al. 2015)

Table 1. Industry classification

	Code of line i	Code of column j	Sector
Normal industry	1	1	Agriculture, Forestry, and Fishery
	2	2	Mining
	3	3	Manufacturing
	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
Petroleum products industry	/	9	Petroleum products industry
	9	/	Gasoline
	10	/	Diesel
	11	/	Other petroleum products
Automotive manufacturing industry	12	10	Normal gasoline vehicle manufacturing sector
	13	11	Normal diesel vehicle manufacturing sector
	14	12	HV manufacturing sector
	15	13	EV manufacturing sector
Energy industry (Electricity)	16	/	Electricity
	/	14	Thermal power
	/	15	Nuclear power
	/	16	Hydro power
	/	17	Solar power
	/	18	Wind power & others
Transport industry	17	19	Railway transport
	18	20	Road transport
	19	21	Water transport
	20	22	Air transport

NOTE: the energy sector can only be categorized as one category within the lateral classification, because the product of energy industry is electricity, whether it comprises thermal power or other power sources. However, the vertical table can be divided into five sectors according to different power sources.

Table 2. Scenario case setting

	GHG emission tax	Subsidy to HV	Subsidy to EV and infrastructure	Subsidy to Clean Energy sector	Thermal power vintage
Case 0	×	×	×	×	×
Case 1	√	√	×	×	×
Case 2	√	√	√	×	×
Case 3	√	√	√	√	×
Case 4	√	√	√	√	√

Note: "√" indicates policy introduced and "×" indicates without policy

4. Models

4.1 Objective Function

The object of the model is to maximize total GDP within 11 years from 2010 to 2020. Considering GDP comparability and inflation effects it is necessary to include a discount for GDP each year. So the discount rate is set at 5%, which is the average inflation rate in China in recent years. GDP is the summary of added value in the I-O table, which consists of income, depreciation and indirect tax.

En means endogenous volumes calculated by computer. *Ex* means the exogenous volumes already set.

$$MAX = \sum_{t=1}^{11} \frac{1}{(1+\rho)^{t-1}} GDP(t) \text{ (t=1, 2010; t=11, 2020)} \tag{1}$$

$$GDP(t) = \sum \{Y_j(t) + D_j(t) + P_j \tau_j X_j(t)\} \tag{2}$$

ρ: Social discount rate *(Ex scalar)*

Y_i: Income of sector i *(En vector)*

D_i: Depreciation of sector i *(En vector)*

P_i: Price change rate of sector i *(En vector)*

τ_i: Indirect tax rate of sector i *(Ex vector)*

X_i: Product of sector i *(En vector)*

4.2 Socio-economic Model

The socio-economic model consists of four parts, known as balances: material balance, value balance, energy balance and fiscal balances. Which reflect the position and the role of government and consumers in socio-economic activities.

4.2.1 Material Balance

The material balance reflects the relationship between supply and demand based on an I-O supply & demand model. EV infrastructure construction investments (*IF*) are available for case 2, case 3 and case 4. The market is assumed as a perfect competition market in this research. Therefore, the supply is assumed equal to or greater than demand to remove irrational results.

$$X_i(t) \geq \sum A_{ij} X_j(t) + C_i(t) + G_i(t) + \sum Q_{ij} \Delta K_i(t) + E_i(t) - M_i(t) + IF_i(t) \tag{3}$$

A_{ij}: Input coefficients of goods or/and services i to sector j *(Ex matrix)*

C_i: Private consumption of goods or/and services i *(En vector)*

G_i: Governmental consumption of goods or/and services i *(En vector)*

Q_{ij}: Input coefficients of goods for the capital stock formation from sector i to sector j *(Ex matrix)*

ΔK_i: Capital stock formation of sector i by each sector *(En vector)*

E_i: Export of sector i *(En vector)*

M_i: Import of sector i *(En vector)*

IF_i: EV infrastructure construction investment from sector i *(En vector)*

4.2.2 Value Balance

The value balance is the longitudinal model based on input-output model, and it expresses the relationship between industry revenue and expenses. Since unreasonable supply and demand in the material balance has been excluded, namely, the situation whereby the supply is lower than demand has been removed, and therefore the appropriate situation must be adopted in value balance, whereby, revenue is equal to or less than expenses. The investment generates revenue to further increase production, which is achieved by accumulating capital (*K*). Similarly, when the number of vehicles in the automobile industry is associated with industrial capital the automobile growth predicted in the model can avoid unreasonable explosive growth. The GHG emission tax is based on industrial emissions, and the industrial emissions are based on the product of emissions per unit output value and its output value. The GHG emission tax rate is an endogenous value with the unit of Yuan/ton. Subsidy (τ_j^S) is available for HV, EV, solar power and wind power only. The price change rate means the products from a sector to other sectors compare with the base year. So the price change rate of this sector to other sectors is the same in a period. For example, for $P_{i1}=P_{i2}=\cdots=P_{ij}$, P_i is be used to express this.

$$\begin{aligned} P_j(t)X_j(t) + \tau_j^S \ \le\ & \sum P_i(t)A_{ij}X_j(t) + Y_j(t) \\ & + P_j(t)\delta_j K_j(t) + P_j(t)\tau_j X_j(t) + E_{cj}\tau_c X_j(t) \end{aligned} \tag{4}$$

δ_j: Depreciation rate of sector n in normal industry *(Ex vector)*

K_j: Capital stock of sector j *(En vector)*

E_{cj}: GHG emission coefficient of sector j *(Ex vector)*

τ_c: GHG emission tax rate *(En scalar)*

τ_j^S: Subsidy to j sector*(En scalar)*

4.2.3 Energy Balance

The energy balance expresses the balance between electricity supply and electricity consumption.

$$\mathrm{b}X_e(t) \ge \sum B_j X_j(t) + C_e^{'}(t) + G_e^{'}(t) + E_e^{'}(t) - M_e^{'}(t) + D^e \tag{5}$$

b: Energy production rate per product in energy industry *(Ex scalar)*

B_j: Energy consumption rate per product in sector j *(Ex vector)*

C'_e: Energy consumption rate of household sector *(En vector)*

G'_e: Energy consumption rate of government *(En vector)*

E'_e: Energy export *(En vector)*

M'_e: Energy import *(En vector)*

D^e: Electricity demand of EV *(En scalar)*

4.2.4 Fiscal Balance

Fiscal balance consists of income and consumption, government budget, social investment, saving and capital balance.

Social income is assumed to increase with economic development. Therefore, equation 6 assumes a stable development of social incomes. Disposable income in equation 7 is the remaining income after taxation. Private wealth flows to two destinations: saving and consumption (equation 8 to 10). In this research, social goods & services consumption rate are assumed to be stable based on the Cobb-Douglas consumption function.

$$Y_i(t) \ \ge\ P_i(t)V_iX_i(t) \tag{6}$$

$$Y_k(t) = (1 - \tau^d)\sum Y_i(t) \tag{7}$$

$$P_iC_i(t) = (1 - \beta)Y_k(t)\alpha_i \tag{8}$$

$$\sum \alpha_i = 1 \tag{9}$$

$$S^p(t) = \beta Y_k(t) \tag{10}$$

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

Y_k: Disposable income *(En scalar)*

τ^d: Direct tax rate *(Ex scalar)*

β: Saving rate *(En scalar)*

α_i: Consumption share of goods and services in sector i*(Ex vector)*

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

Government budget (equation 11) reflects the executor position and the role of government. The left items are government income, including direct tax---from the household sector, indirect tax---from industries, GHG emission tax---from industries. The right items are government expenditure, including normal expenditure, government saving and subsidy. Government capital is not considered in this research because the data is unavailable. A GHG emission tax is the special tax in this research. All GHG emission tax income is spent as subsidy, and it is the only source of subsidy (equation 12).The investment in EV infrastructure comes from every sector and total EV infrastructure investment is related to EV amount (equation 32).

All savings are treated as investment to maximize GDP. For the left side of equation 15 are net investment, and the right side is government saving, household saving and net export. Net export here is considered consumption of import goods and overseas travel (*M*), income from export goods and services (*E*).Production in sectors is decided by capital investment (equation 16) based on the Cobb-Douglas production function.

$$\tau^d \sum Y_i(t) + \sum \tau_i P_i X_i(t) + \sum \tau_c X_i E_{ci} = \sum P_i G_i(t) + S^g(t) + \tau^S_{HV} + \tau^S_{EV} + IF(t) + \tau^S_{ES}(t) + \tau^S_{EW}(t) \tag{11}$$

$$\sum \tau_c X_i(t) E_{ci} = \tau^S_{HV}(t) + \tau^S_{EV}(t) + IF(t) + \tau^S_{ES}(t) + \tau^S_{EW}(t) \tag{12}$$

$$IF(t) = \sum_{i=1}^{20} IF_i(t) \tag{13}$$

$$IF_i(t) = IF_i^{'} \cdot IF(t) \tag{14}$$

$$\sum \{\Delta K_i(t) - \delta_i K_i(t)\} = S^p(t) + S^g(t) - \sum \{E_i(t) - M_i(t)\} \tag{15}$$

$$X_i(t) \le \gamma_i K_i(t) \tag{16}$$

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

IF: Total EV infrastructure construction (investment) volume *(En scalar)*

$IF^{'}_i$: EV infrastructure construction (investment) rate of sector i*(En vector)*

γ_i: Capital production coefficient of industry i*(Ex vector)*

4.2.5 Dynamic Equation

The social economy is developed with capital investment in this research. Therefore, capital investment is the engine to move the model simulation and reflect other variables.

$$K_i(t+1) = (1-\delta_i)K_i(t) + \Delta K_i(t) \tag{17}$$

4.3 GHG Emission Model

4.3.1 GHG Emission by Vehicles

The GHG emission model accounts for the total social GHG emission, and considered emissions during vehicle movement, energy generation and industrial production. GHG emissions during the vehicle production phase are included in the vehicle manufacturing sector, and consequently included in the LCA view. Vehicles are classified as normal gasoline vehicles, normal diesel vehicles, HV and EV and correspond to their manufacturing sectors. They are used for private passenger vehicles, private cargo vehicles, transport passenger vehicles and transport cargo vehicles. The vehicle classification totals 16 in this research.

Equation 18 calculates GHG emission from vehicles and consists of two parts: GHG emission of normal gasoline vehicles, normal diesel vehicles and HV in the 4 kinds of usage and GHG emission of EV, which is caused by the emission coefficient of electricity generation. However, the GHG emission coefficients of the energy industry are dynamically treated with in this research. The result is that GHG emission of EV will be decrease with clean energy promotion.

In case 4, a special equation is necessary to define thermal power vintage (equation 20). The vintage rate decreases with the coal consumption rate (CEC 2012). The unit capacity of newly built thermal power should be 600,000 kW and on principle the coal consumption of producing electricity should be controlled at 286 g/kWh coal or less(CEC 2011). The thermal power vintage decreases the GHG emission coefficient of thermal power generation from 966.5 g-CO_2/kWh (2010) to 830g-CO_2/kWh (2019).

$$W_v(t) = \sum_{z=1}^{3}\sum_{d=1}^{4} \mu_z U_z^{-1} L_z^d O_z^d(t) + D^e(t) \sum_{e=1}^{5} R_e^e(t) E_e^{CO_2}(t) \tag{18}$$

$$R_e^e(t) = \frac{X_e^{'}(t)Ic}{\sum_{e=1}^{5} X_e^{'}(t)Ic^e} \tag{19}$$

$$E_1^{CO_2}(t) = \overline{E}_1^{CO_2}(1-r)^{t-1} \tag{20}$$

$$D^e(t) = \sum_{d=1}^{4} U_4^{-1} L_4^d O_4^d(t) \tag{21}$$

W_v: Total GHG emission by vehicles *(En scalar)*

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

U^{-1}_z: Fuel consumption rate of z *(Ex vector)*

L^d_z: Yearly distance of z kind vehicle at d usage *(Ex vector)*

O^d_z: Vehicle amount of z kind vehicle at d usage *(En vector)*

R^e_e: Composition rate of energy e *(En scalar)*

E_e^{CO2}: GHG emission coefficient of energy e *(Ex vector)*

Ic: Average product rate of installed energy capacity *(Ex scalar)*

Ic^e: Product rate of installed energy capacity of energy e *(Ex vector)*

$\overline{E}_1^{CO_2}$: GHG emission coefficient of thermal power at 2010 *(Ex scalar)*

r: Decrease rate of GHG emission coefficient of thermal power *(Ex scalar)*

4.3.2 GHG Emission from Industry

GHG emission from each sector is based on the production and emission coefficient. Sector No.20 is the road transport sector and is expressed by vehicle emissions.

$$W_c(t) = \sum_{j=1}^{22} E_{cj} X_j(t) - E_{c20} X_{20}(t) + W_v(t) \tag{22}$$

W_c: Total GHG emission in China *(En scalar)*

4.3.3 GHG Emission Constraint

GHG emission per GDP (EpG) is the only GHG emission constraint in this research and is set to achieve the Chinese government target released at COP15. EpG can be treated as an environmental trait per GDP or an economic trait from an environmental viewpoint. EpG is assumed to decrease in each term, to match the target by 2020. *n%* means the decrease rate of EpG in each term.

$$EpG(t) = \frac{W_c(t)}{GDP(t)} \tag{23}$$

$$EpG(t+1) \le (1-n\%)EpG(t) \tag{24}$$

EpG: GHG emission per GDP *(En scalar)*

4.4 Vehicle Estimation Model

The Vehicle estimation model defines vehicle amount, subsidy, vehicle distribution, EV and EV infrastructure investment, the relationship between vehicle numbers and its manufacturing sector. Vehicle amount predictions are based on the production of its manufacturing sector overall. Increasingly, vehicles are produced by the vehicle-manufacturing sector and must be connected to achieve a genuine simulation result. In addition, the average annual vehicle increase rate was 17.3% from 2000 to 2012 (NBSC 2014), therefore the vehicle increase rate is assumed to be within 5%-20%.

$$O(t) = \sum_{z=1}^{4}\sum_{d=1}^{4} O_z^d(t) \tag{25}$$

$$O_z^d(t+1) = O_z^d(t) + \Delta O_z^d(t) - Od_z^d(t) \tag{26}$$

$$\sum_{d=1}^{4} \Delta O_3^d(t) = \tau_{HV}^S(t) I_{HV} \tag{27}$$

$$\sum_{d=1}^{4} \Delta O_4^d(t) = \tau_{EV}^S(t) I_{EV} \tag{28}$$

$$Od_z^d(t) = pd_z^{-1} O_z^d(t) \tag{29}$$

$$\Delta O^d(t) = R^d \Delta O^1(t) \tag{30}$$

$$X_z(t) = AP_z \sum_{d=1}^{4} \Delta O_z^d(t) \tag{31}$$

$$IF(t) \geq IFV \sum_{d=1}^{4} \Delta O_4^d(t) \tag{32}$$

O: Total vehicle amount *(En scalar)*

$\Delta O^d{}_z$: Increased vehicle amount of z kind vehicle at d usage *(En vector)*

$Od^d{}_z$: Decreased vehicle amount of z kind vehicle at d usage *(En vector)*

$\Delta O^d{}_3$: Increased HV amount at d usage *(En vector)*

I_{HV}: HV increase rate based on subsidy *(Ex scalar)*

$\Delta O^d{}_4$: Increased EV amount at d usage *(En vector)*

I_{EV}: EV increase rate based on subsidy *(Ex scalar)*

$pd^{-1}{}_z$: Depreciation rate of z kind of vehicle *(Ex vector)*

R^d: Distribution rate of vehicle at d usage *(Ex vector)*

AP_z: Average price of z kind of vehicle *(Ex vector)*

IFV: EV infrastructure demand rate *(Ex scalar)*

5. Results and Discussion

5.1 GDP and GHG Estimation

Overall, in addition to Case1-0.5% is slightly higher than Case 0 in 2020, the GDP of the rest of the cases in the past years were lower than Case 0 without any policy introduction. In other words, under the premise of no technological changes, the GDP will be reduced with any environmental policy introduction.

With the strengthening of environmental constraints, when the operating variable *n* (equation 24) is increased to 0.8, there is no solution for Case1. The range of variable *n* is 0-0.6 in Case 2, 0-1.9 in Case 3 and 0-2.6 in Case 4. Consequently, there are several simulations for each case under different operating variables *n*. In Case 1-0.7%, the growth of GDP is suppressed because of the high environmental constraints, which is the obvious reflection of game relations focusing on the economy but damaging the environment. The GDP growth in Case 1-0.6% from 2010 to 2018 is close to case 0, but will decline after 2019 as the emission reduction effect of HV introduction will reach its limit in 2018. This will be unable to make EpG began from 2019 maintain an annual decrease of 0.6%, thereby forcing a reduction in production to meet environmental goals. Therefore, the policy introducing HV only under the average annual EpG reduction of 0.5% does not affect the GDP limitation. As a result a growth trend of HV in line with law of market changes can bring China a maximum average annual EpG decline of 0.5%, where the best situation reflects Case 1 at an operating variable of 0.5. For a clear comparison with each scenario and different policy, only the best situation in each case will be considered in the following analysis. Where the operating variable *n* is 0.6 in Case 2, 1.9 in Case 3 and 2.6 in Case 4.

Due to the control of vehicle growth trend in the vehicle growth model, defining the vehicle growth within a certain range, results in the introduced number of HV annual growth not being explosive, thus the GHG reduction effect of HV does not obviously reflect Case 1.The relatively lower GDP growth curves and higher GHG emission curves in Case 2 is shown in Fig.2 and Fig.3. This is not a good choice to increase EV into the status quo under conditions of limited electric power upgrades, and it is essential to reduce production despite the aim to achieve environmental goals. The total GDP value of Case 4 was only 0.01% higher than Case 3, which suggests that the "upgrade" of thermal power quality does not create any changes in socio-economic structures, but lowers GHG emission.

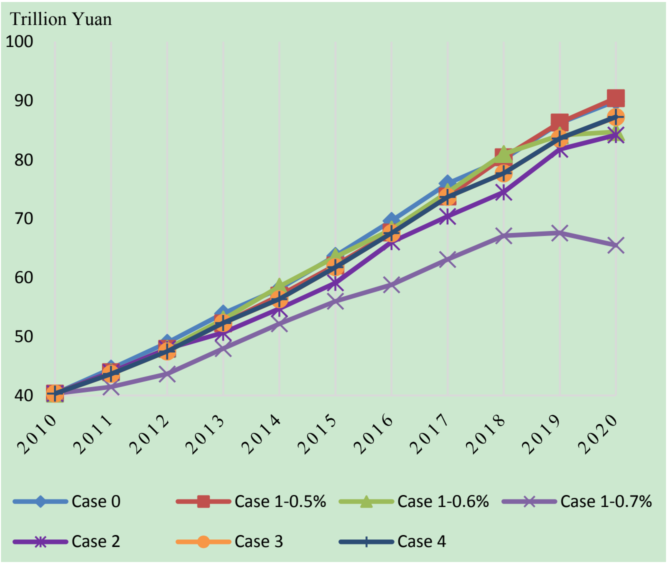

Figure 2. GDP growth trend for each case

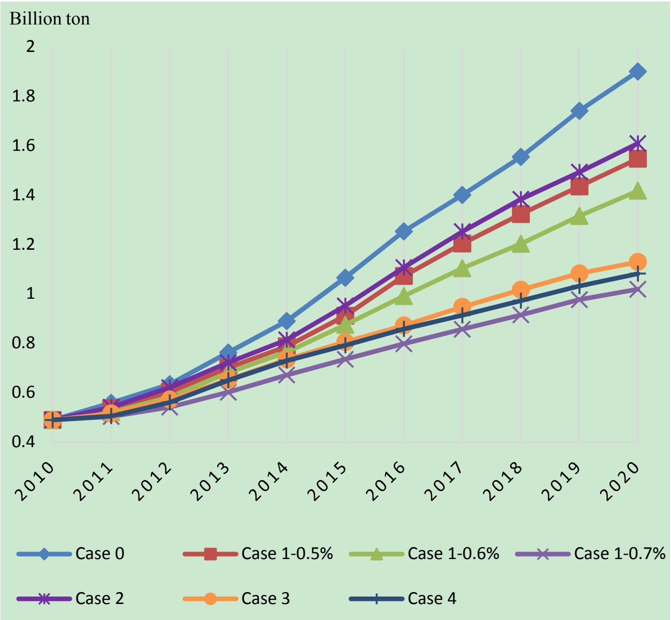

Figure 3. GHG emission trend by vehicles in each case

5.2 GHG Emission per GDP

The EpG in 2005 is calculated to be 0.0002776 ton/Yuan by referring to the GDP (NBSC 2006) and GHG emissions (MEPC 2006)in 2005. If the assumed government environmental goal of 0.0001527-0.0001666 ton/Yuan can be achieved by 2020, then the average annual EpG reduction needs to be at least 3.1%-2.2% from 2010, namely, the government environmental goals can be accomplished as long as there is an average annual EpG decline of at least 2.2%.

The EpG trend displayed by the four situations in Case 1 and Case 2 are very similar, which is slightly lower than that of Case 0. As shown in Fig.4, HV promotion and EV promotion through ignoring electricity reform cannot effectively reduce GHG emissions per unit of GDP, and the corresponding EpG are almost the same. It is obvious that their roles are limited in improving the environmental quality of the socio-economy. Case 3 is close to the target value. While promoting HV and EV, the power sector emissions can be improved through the use of clean energy with low-emission. EpG is successfully reduced year after year, and will basically approach the government's environmental goals in 2020. However, even if the three-pronged approach is adopted, the EpG in

2020 will be only 0.000168 ton/Yuan, and this will not achieve the goal, thereby requiring further policy change. With the implementation of this evolutionary policy, GHG emissions in thermal power has been refined, producing a reduction in EpG year after year, and reaches the government's goals in 2018. Thereafter EpG will continue to decrease, EpG will be reduced to 0.000159Ton/Yuan in 2020, reaching the goal of reduced by 40%~45% in 2020 compared to that of 2005, an ultimate reduction of 42.55% EpG.

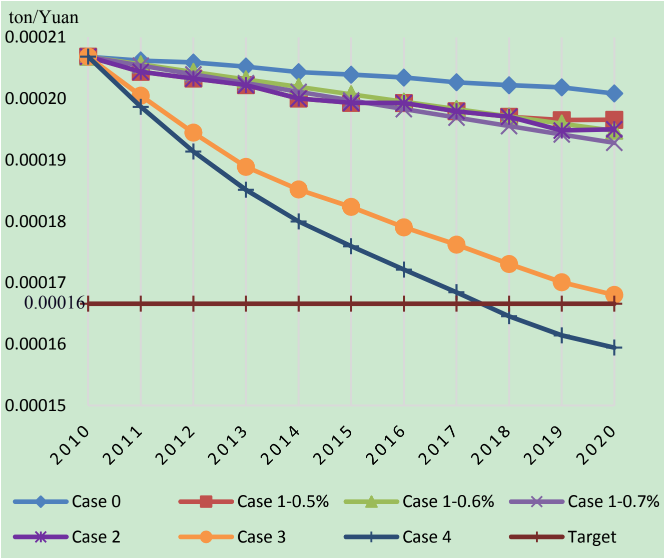

Figure 4. GHG Emission per GDP in each case

5.3 Simulated Vehicle Situations

The new added vehicle parc is associated with output value of the corresponding automobile manufacturing industry, and thus the change in vehicle parc is limited to the development of automobile manufacturing industry. The vehicle parc of Case 0 increases rapidly during the development of the conventional automobile industry and without the environmental pressure on GHG emission reduction, the vehicle parc will reach 195 million in 2020 with an average annual growth rate of 9.8%. The government forecast of China's official vehicle parc in 2020 is 200 million vehicles, indicating that the model of this dissertation in predicting vehicle parc basically coincides with the government forecast.

Because of policy support for HV & EV, it occupies part of the conventional automotive market, but it does not reflect on overall change trend of vehicle parc. The most important factor affecting vehicle parc growth rate is the pressure of GHG emission reduction (Fig.5). The vehicles reduction directly reduces the vehicle GHG emissions. Furthermore, the slowdown automobile growth rate also directly reduces production in the automobile manufacturing industry, and reduces the production demands of all related industries, thereby further reducing overall emissions.

Despite the limited number of environmentally friendly vehicles, greater growth is realized (Fig.6).By taking Case 4 that is the only case achieving EpG reduction target for an example, the vehicle parc of HV in 2020 will be 1.072 million, which will be 454,000 more than that of Case 0, an increase of 73.5%. The vehicle parc of EV will be 423,000, which will be 224,000more than that of Case 0, an increase of 113%. The annual increase rate will be 39.1% for HV and 42.3% for EV. In Case 1 by only introducing HV, more HV will be promoted with the improvement in environmental constraints, which is in line with the goal of reducing the GHG emissions through HV, which proves the validity of the model. In Case 2, the number growth of EV also reflects this fact. However, an unexpected result is that the number of HV and EV decreased compared with Case 2 after re-allocating the grants to the new energy electric power industry. The cause is that the emission reduction effect of the power sector is even more effective than the promotion of HV and EV, thus the model of pursuing optimal solution chooses to reduce HV and EV grants.

According to JAMA data (JAMA 2014) of Japan, the vehicle parc of HV during the 11 years from Japan releasing HV into the market in 1999 to 2010 was 984,000, and this number grew to 3.84 million until 2014, the annual increase rate was 49.6% and 40.5%respectively; EV increased to 39,000 during the period from year 2011 to 2014, the annual increase rate was 16%. Based on the experience of developed countries, the results in this research are consistent with the law of market development, and its achievement in terms of EV is even higher than that in Japan.

Figure 5. Vehicle parc changes in each case

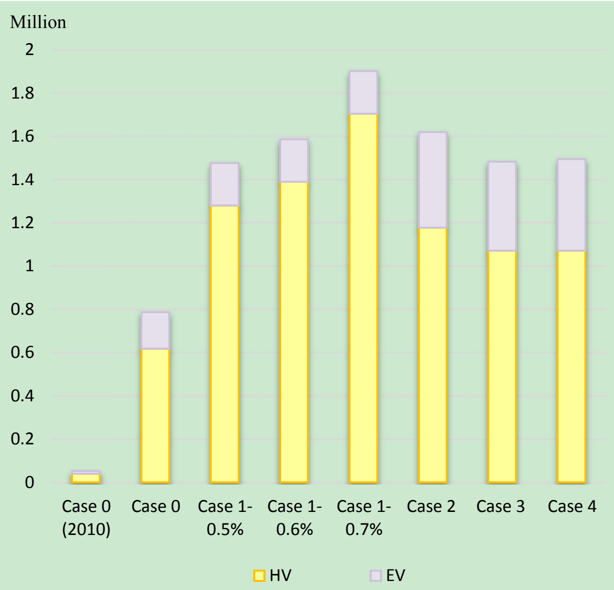

Figure 6. HV and EV amount at 2020

5.4 GHG Emission Tax and Subsidy

GHG emission taxes and subsidies are the main driving forces of the policy study in this research. The levy of GHG emission taxes in all social sectors corresponding to their emissions, are used as the grants to promote the development of EV, HV and clean energy power industry, but also drive the power of "maximized self-interest" (Paul R.K 2012) of each individual in the socio-economy to reduce their GHG emission taxes or reduce emission rates to achieve the purpose of enhancing the corresponding environment efficiency economically.

In Case 1, the different environmental constraints enhance its GHG emission taxes with the stronger restrictions, from 0.3825 Yuan/ton to 0.4187 Yuan/ton and then to 0.5631 Yuan/ton. The corresponding amount of subsidiaries is 52.3 billion, 57.3 billion and 65.3 billion respectively. Therefore, the stronger environmental restrictions mean a higher GHG emission tax rate. Although the higher GHG emission taxes mean more grants, they do not reflect a linear relationship. The GHG emission tax in Case 2 is 2.5138 Yuan/ton, which is 6.5 times more than that of Case 1-0.5%, however, its total grant is 141.5 billion Yuan, which is only 2.7 times of the Case 1-0.5%. The reason is that other social industries are changed through the promotion of EV and HV, which affect the total production of the community simultaneously, thus to make the re-integrated social industry have a higher environmental quality. The subsidy amount for HV in Case 2 is 48.4 billion Yuan, accounting for 34.2% of the total amount; the subsidy amount for EV is 33.5 billion Yuan, accounting for 23.6% of the total amount; the subsidy amount for EV infrastructure is 59.6 billion Yuan, accounting for 42.2% of the total amount. It is noticeable that when introducing EV, the construction of EV infrastructure (charging stations, charging piles, etc.) will cost more.

After considering the subsidy of the new energy electric power, either Case 3 or its evolutionary version of Case 4, both reflect a leap forward in the growth of GHG emission tax rate and the subsidy amount. The reason is that the GHG emission reduction is in effect brought about by subsidizing electric power and is much higher than the corresponding impact on the economy. After the optimization calculation, the final GHG emission tax is 15.8917 Yuan/ton in Case 4. The total subsidy amount is 2.711 trillion Yuan. Its distribution rate is: HV1.6%; EV1.2%; EV infrastructure construction 2.1%; solar energy 48.1%; wind power 47%. Namely, the grants are mainly put into the clean energy power industry of solar energy and wind power to reduce optimum efficiency of GHG emissions in China.

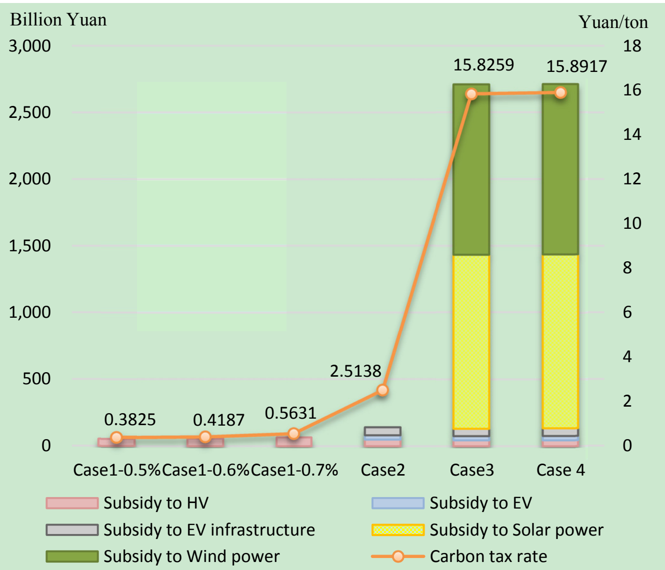

Figure 7. Total subsidy and their spend way & GHG emission tax rate

5.5 Clean Energy Promotion

The development of the power industry discussed in this section concerns the best power development in Case 4. The total electric power installed capacity in 2010 was 961 GW, and this will be increased to 1953 GW in 2020. Despite the vigorous development of new energy from 2010 to 2020, the production value of thermal power is still on the rise, and its share in the power industry decreased from 82.8% in 2010 to 63.8% in 2020 (Fig.8). In the next 10 years, thermal power will still occupy the mainstream of China's power. The nuclear power and hydropower are not the development goals of Case 4, so the nuclear power dropped from 3.4% to 3%, although the ratio declined, the production value increases; hydropower increased from 12% to 17.9% with a slow pace of development. Under the situation of no grant support, the development of nuclear power and hydropower will be very limited. As for the solar energy supported by the policies, it developed from accounting for 0.7% of the total amount of the power industry in 2010 to 5.1% in 2020. The corresponding installed capacity increased from 4.4 GW to 100 GW, an increase of 2172%; and its production value increased from 26.9 billion to 612.5 billion with an increase of 2177%. Wind power also shows substantial development, accounting for 1.1% of total amount in power industry in 2010 to 10.2% in 2020, and its installed capacity increased from 17.9 GW to 200 GW, an increase of 1017%; its production value rose from 42.5 billion to 473.5 billion with an increase of 1014%. Overall, the proportion of sustainable energy increased from 17.2% in 2010 to 36.2% in 2020.

Through grant support of the solar power and wind power, it can be clearly seen that GHG emission coefficient of the power industry fell from 785 g/kWh in 2010 to 599 g/kWh in 2020, which is close to power emission level of Japan's 596 g/kWh in 2010 (OECD 2011), and there is still great potential for further development. In addition, it is clear that GHG emission tax-subsidy policy worked well to promote target sectors: HV and EV manufacture sector promoted 73.5% and 106.4%; nuclear power increased 74.1%; solar power promoted 524%; wind power increased 124.6% (Fig.9).

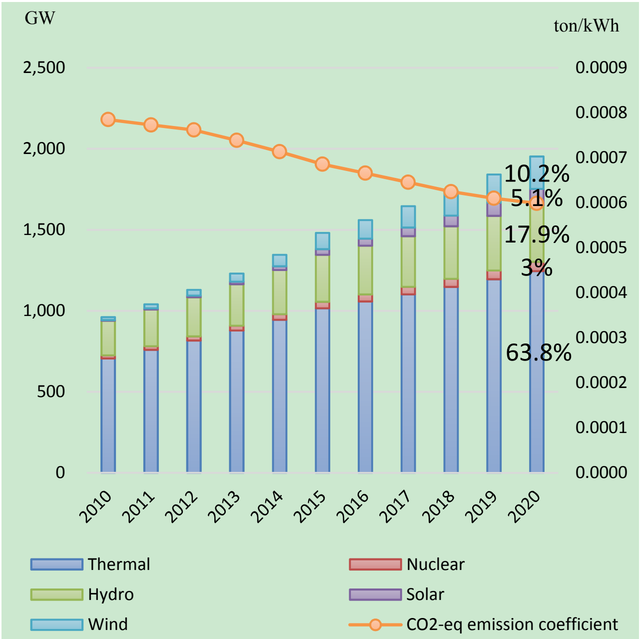

Figure 8. Composition of installed energy capacity & CO_2-eq emission coefficient

6. Conclusions and Policy Implications

The Chinese government established China's GHG emission reduction target when attending COP15 of the UNFCCC: the GHG emissions per unit of GDP in 2020 will be reduced by 40%-45% compared to that of 2005.Withthe summary and examination of the current GHG emission situation in China, this research considers that it is essential to adjust the quantity and quality of China's vehicles to cope with economic and environmental development requirements in the future. Through the governmental introduction of a GHG emission tax, the GHG emission taxes will be used as the financial source of grants to promote the development of environment friendly vehicles and clean energy, thus achieve the purpose of sustainable development by reducing GHG emissions. In practice, the GHG emission tax rate is considered to be the most important policy fulcrum. Through model building, the linear optimization software calculated the optimum GHG emission tax in terms of economic and environmental aspects.

In order to conduct a comparison of policy effectiveness, this research simulated four cases of policy effects in respective: Case 1 is to lower GHG emissions by using HV only; Case 2 of using HV and EV simultaneously; Case 3 of subsidies and development of the electricity industry while using HV and EV; As for Case 4, thermal power will be reformed and evolved from the original basis to calculate the emission reduction potential of this policy.

Many results can be concluded based on simulation result analysis. In case of no policy introduced (Case 0), the predicted GDP volumes (2010-2014) are similarly to real level published by China government within 5% difference only. Additionally, vehicle parc at 2020 is predicted in this case at same level with MIIT prediction within 2.9% difference. Therefore the model accurately estimates the economic and vehicle situation in this case

If a GHG emission tax is adopted to promote HV industry (Case 1), the emission of GHG can be decreased in the short term but it is impossible to clear GHG reduction target. The model strived to reflect reality, and therefore the increasing number of vehicles is based on market changes and the annual growth in the number of vehicles is linked to the output of the annual vehicle production industry. Due to the maximum overall economic and limited environmental emission reduction, the industries with high emission will be restricted from production. Meanwhile, the model opens a "channel" to facilitate effective emission reduction by reducing the number of traditional fuel vehicles and introducing HVs, EVs and new energy, so this "channel" will be prioritized by the model. The slowdown in vehicle growth will directly reduce the production of vehicle manufacturing and reduced the production needs of all associated industries, thereby further reducing overall emissions. This is the main reason for the ineffective GHG reduction effects of HV introduction.

The result for Case 2, which proposed EV promotion, showed an interesting conclusion that it is inefficient to promote HV & EV at same time without clean energy promotion. However, regardless of HV & EV promotion, they are powerless to decrease GHG emission per GDP (EpG).

A different effect occurred when clean energy is subsidized (Case 3), Case 3 has enough "reason" to complete the environmental objectives, and the huge effects of power sector reform make the impact of policies on the economy to be limited to only the levy of GHG emission taxes. The levying mechanism and effect of GHG emission taxes is very simple, because the GHG emission tax is fair on "levying by emissions", therefore, the self-interest principle of the socio-economy will be used effectively, thereby ultimately forcing high emission industries to improve their emission efficiency or reduce production, in order to make the industries seek the most favorable balance between production and taxation. From a macro viewpoint, along with introduction of a GHG emission tax, all industries will experience environmental reform, the GHG emissions will be reduced year by year. Consequently, EpG was significantly decreased from 207 ton/million Yuan to 168 ton/million Yuan but is still not enough to attain the environment target.

Therefore an upgrade of thermal power is necessary as suggested by Case 4. This policy proposal is finally attained by the Chinese government environmental target in 2020, with 8.02% annual GDP increase rate and big promotion of clean energy. The most optimal GHG emission tax rate is calculated as 15.8917 Yuan/ton. EpG will be reduced to 0.000159 ton/Yuan, thereby the ultimate reduction of 42.55% by 2020 compared to 2005. The electricity emission coefficient will decrease from 785 g/kWh in 2010 to 599 g/kWh in 2020, a decline of 23.7%. According to the dynamics of the model, GHG emission of EV will continue to decrease year by year and make EV as the real “zero emission” vehicle in the future. It is certain that the long-term policy implementation of Case 4 will be a recommended solution to deal with the GHG problem in China.

Ultimately, policy makers must pay more attention to the energy industry when considering GHG emission issues. Clean energy promotion is proved in this research as the best option for the future. It will revitalize not only EV but also facilitate any energy-related industries to increase the economic quality of environment.

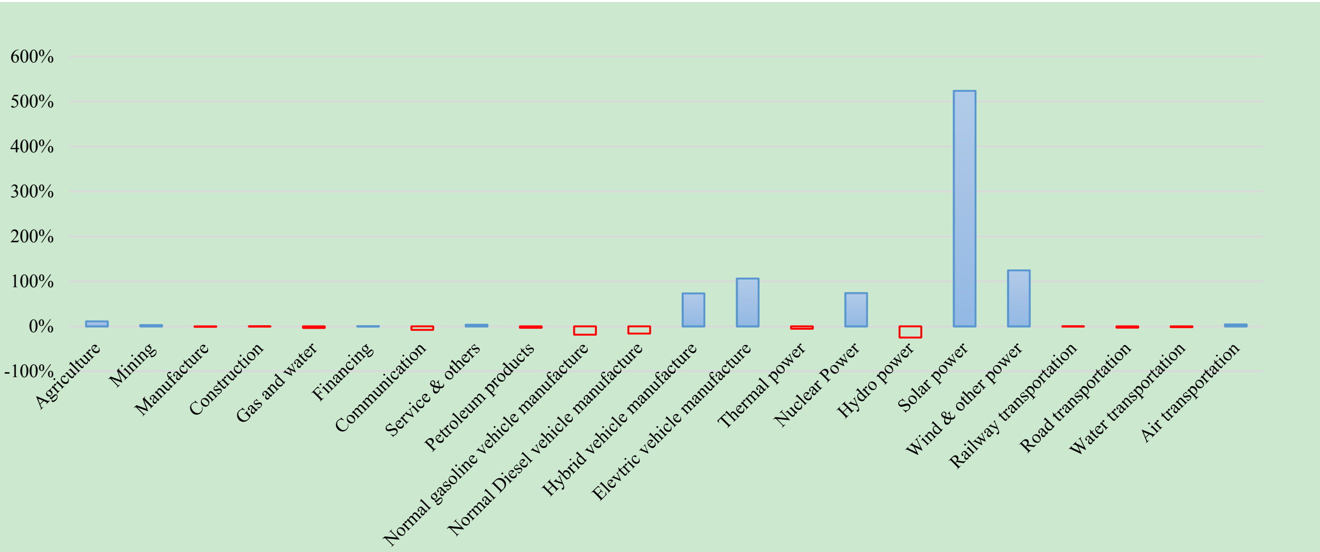

Figure 9. Total production change rate of Case 4 based on Case

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