Exploration of the Growing Trend of Electric Vehicles in Beijing with System Dynamics method and Vensim model

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Abstract

This research is conducted to explore the growing trend of private vehicles in Beijing, China, in the coming 25 years using the system dynamics (SD) method. The vensim software is used to build the SD model and do simulations. First, the paper introduces the background of the private vehicles in Beijing and analyzes the issues of traffic congestion and air pollution caused by them. Second, the method system dynamics is justified to analyze the concerned issues of Beijing vehicle and the attendant traffic congestion and air pollution. Third, qualitative analysis is done to explore what possible policies the Beijing government can adopt to increase the percentage of electrical vehicles (EVs) and control the number of total private vehicles at the same time. A causal loop diagram is drawn to facilitate the way of thinking. Afterwards, a quantitative SD model about the system is built based on the causal loop diagram and qualitative analysis is made. Finally, the SD model is simulated to explore the plausible future trend about private vehicles and study the implications of different policies.

Key words: *system dynamics; vensim; Beijing; electric vehicle; air pollution; traffic congestion*

1. Introduction

1.1 Research background

Beijing has been facing severe air pollution since the end of 2012. According to "*The Guardian*" news(Vaughan, 2013), all over 2013, only 13 days in Beijing is considered "good" based on the US index, while 70 days moderate air pollution, 64 days unhealthy for sensitive groups, 148 days unhealthy, 45 days very unhealthy, 14 days hazardous and one day "beyond index", ie., off the scale. The primary cause is the huge amount of pollutant emission, among which vehicle emission ranks second after industrial emission.

Another significant problem caused by private vehicles in Beijing is traffic congestion. In the past decade, the number of private vehicles in Beijing has increased from 1.5 million in 2000 to 4.1 million in 2013, which made a great contribution to the economy increase, but in the meantime, the traffic in Beijing is badly affected with such a huge number of vehicles (Wikipedia, 2012).

The Beijing government is putting great effort in alleviating the pollution and traffic congestion. To control the increase of vehicles, the ‘license plate lottery’ policy (Lim, 2011) has been implemented since 2011. Since the implementation of this policy, citizens who want to get a new license plate to buy a vehicle must register online and join the lottery. Every month a certain number of license plates are issued to these registers randomly. License plate lottery policy is chosen as the first base policy in this paper. To encourage citizens to buy EV, citizens can join a lottery special for EV and the chance to get an EV license plate is higher than for conventional vehicles (CVs). Besides, the Beijing government provides about 40% subsidy to those who buy EV.

One interesting policy about private vehicles in Beijing is that some private vehicles are not allowed to be on road on weekdays. For instance, those vehicles whose license plate number ends with 0 or 6 are not allowed to be on road on Monday, and number ending with 1 or 7 on Tuesday, etc. This policy is chosen as the second base policy in this paper.

Currently, two hot debates are undergoing. One is whether the restriction should be only on CV. In other words, some citizens propose that those who want to buy EV have no need to join the lottery to get the license whenever they want. The other is whether the Beijing government should adopt the license plate policy as in Shanghai (Yue, 2013). In Shanghai, there is also restriction on new license plates; however, it takes place in form of auction. Citizens who want to get a license plate should participate in an auction rather than join the ‘license plate lottery’ process in Beijing. Shanghai citizens have no need to wait for years like in Beijing to get a new license plate but they need to pay about 70000RMB (Yue, 2013) for a license plate. The paper will use quantitative system dynamics model to explore the advantages and disadvantages of the two policies.

1.2 Research method

A lot of studies on transportation and traffic congestions applying system dynamics have been conducted by researchers, among which are (Springael, 2002) and (Barlas, 2002). In terms of air pollution, many researchers have also been done with system dynamics method, a good example is (Hamed, 2014). In our research, system dynamics is also used to explore the relationship of private vehicles, traffic congestion and air pollution.

System dynamics is a discipline emerged in late 1950s, which attempts to explore complex long-term policies in both public and private domains (Sterman, 2000). It is a tool to help address complex issues involving delays, feedbacks and nonlinearities. As the real world is a multi-loop, multi-state, non-linear feedback system (Forrester, 1969), system dynamics provides a scientific way to facilitate our thinking of the complex world.

Causal loop diagram is a tool to understand the dynamic, interrelated nature of the real world. By linking together the key variables, the causal relationships between them are indicated. By stringing together several loops, a coherent story about a specific issue can be depicted (Kim, 1999).

Vensim is a visual system dynamics s simulation modelling tool, with which users can conceptualize, document, simulate, analyze, and optimize models of dynamic systems (Ventana, 2010). Based on causal loop diagram, a simulation model can be built in the vensim environment, in a presenting form of stock and flow diagram. Relations among system variables are built and recorded by connecting words with arrows. When completed, the model can be simulated, analyzed and its behaviours can also be explored thoroughly by users (Akhtar, 2011).

In this paper, system dynamics thinking is applied both qualitatively and quantitatively. First, qualitative analysis is done to explore what possible policies the Beijing government can adopt to increase the percentage of EV and control the total number of private vehicles simultaneously; Second, causal loop diagram of the private vehicle market in Beijing is drawn to facilitate the way of thinking; Finally, SD model using vensim software is built to explore the plausible future trend about private vehicles and implications of different policies.

1.3 Research questions

More private vehicles will lead to more traffic congestion, and more CVs will cause more air pollution. Hence, to solve the two problems, on the one hand, the total number of private vehicles should be controlled; on the other hand, the percentage of EV should be increased. Basically, the research is focused on these two aspects.

The first aspect is about solving the traffic problems in terms of private vehicles: What policy can be applied to control the total number of private vehicles?

What policy can be applied to control the total number of private vehicles on road?

The other aspect is aimed to solve the air pollution caused by conventional vehicles: What policy can be used to increase the percentage of EVs? What policy can be used to decrease the number of CVs on road?

2. Problem qualitative analysis

In this part, the research questions raised up above are first analyzed with basic logic and brainstorming. Then causal loop diagram is built based on the analysis, which in return will be the foundation of the system dynamics (SD) model.

2.1 Qualitative analysis of the research questions

(1) *Reasons why there are so many private vehicles?*

Beijing is facing a high speed of economic growth and a fast trend of urbanization, thus more and more people in Beijing can afford to buy a vehicle. Even though problems such as air pollution and traffic congestion are severe in Beijing, the total population in Beijing might continue increasing in the near future due to its economic and political attractiveness.

(2) *What policy can be applied to control the total number of private vehicles?*

The basic policy used by the Beijing government to control the total number of vehicles is to restrict the license plates issued per year. 240,000 license plates are issued per year from 2011 to 2013, 88% of which are for private vehicles. From 2014 to 2017, the Beijing government plans to decrease the number from 240,000 to 150,000 per year (Wei, 2013). Data shows that the growing rate of private vehicles in Beijing becomes slower in recent years, proving the usefulness of this policy. Further discussions will be made to decide how many private license should be issued per year in the future to act optimally.

(3) What policy can be applied to control the total number of private vehicles on road?

In order to decrease the total number of vehicles on road, only part of the vehicles are allowed to be on road on a certain week day. The current policy in Beijing is that only 80% of the private vehicles are allowed to be on road everyday as mentioned in the introduction part. It is assumed in this paper that EV generates no pollution. In practice, however, most the electricity energy comes from fossil fuels, which indeed pollutes the air. However, these power plants are far away from Beijing, thus the impact on Beijing air can be neglected. The increase proportion of EV, therefore, will lead to less air pollution.

(4) Reasons why EVs are not popular in Beijing?

There are several reasons why EVs are not popular in China. The first one is that the EV price is relatively higher than that of CV due to the immaturity of the EV technology. The second reason is that the driving range is relatively smaller than CV. Furthermore, the infrastructures for EVs are not sound yet, adding to inconvenience for people using EVs (Wikipedia, 2012).

(5) What policy can be used to increase the percentage of EVs?

First, the government will subsidy the EV purchase while tax on CV; Second, the government need to build more charging stations to provide enough access to EV battery charge. Besides, the idea of environmental friendliness is suggested to be propagandized to raise the consciousness of the public. As to the driving range, it is quite uncertain since it depends on the technology level. Scenarios analysis about technology level will be made in later part of the research.

(6) What policy can be used to decrease the number of CV on road?

As mentioned in (3), the policy to decrease the total number of private vehicles on road is to allow only part of the private vehicles every day. For CV specifically, a more restrict policy can be applied to restrict the CVs on road.

2.2 Causal loop diagram based on qualitative analysis

The development of the vehicles is fundamentally influenced by factors in three aspects: market discipline, government policies and population growth. The factors acting on market discipline include technology level, vehicle price, oil and electricity prices, and maintenance cost. The government policies include the installation of charging stations, subsidy for EV, additional tax on CV, and the license-plate lottery, etc. The population also plays an important role in the increase of private vehicles. An increase in population will lead to an increasing need for private vehicles, leading to worse traffic congestion and air pollution. The worse air pollution and traffic congestion, in feedback, might reduce the growth rate of the population.

To facilitate thinking, a causal loop diagram is shown as in Figure 1. The most important loop in the figure is the positive loop in the figure. More EV charging stations cause larger percentage of citizens wishing for EV, which causes more EV possession; more EV possession leads to more need for EV charging stations.

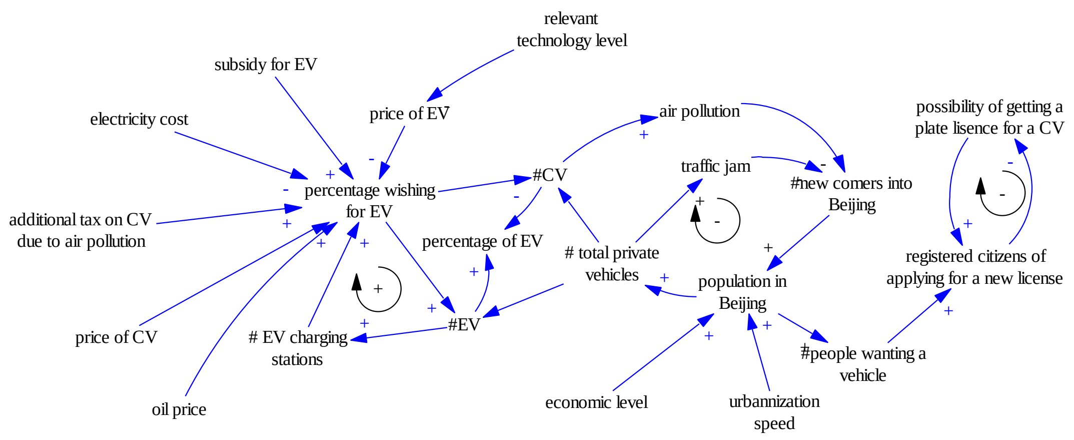

Fig.1 causal loop diagram

3. Model building with vensim

In general, there are two common functions of model building. One is to explore the plausible further; the other one is to study the implications of different policies (Pruyt E., 2013). In this paper, the first purpose of model building is to explore the plausible future trend of private vehicles, both EVs and CVs. Based on that, the policies mentioned above are tested whether they will actually work to improve the percentage of EVs while restrict the total number of private vehicles simultaneously. The model is policy oriented instead of imitating the reality.

3.1 System Boundary

This research is aimed to explore the developing trend of private vehicles including both CVs and EVs within Beijing with a time horizon of 25 years from 2013 to 2038. The monetary currency used is Chinese RMB.

The CVs includes the conventional vehicles and normal hybrid electric vehicles (HEV) since 90 percent of the energy source for HEV is oil. The EVs includes pure electric vehicles and plug-in HEV (PHEV), whose energy source is mainly form electricity.

Only private vehicles are taken into account in this paper. Private vehicles account for about four fifth of total vehicles in Beijing.

The growth of population contributes a lot to the increase of total private vehicles. However, the population growth rate is not only affected by the air pollution and traffic congestion, but also affected by many other factors (Li, 2013). In the SD model, there is no feedback from traffic congestion and air pollution. Instead, scenario analysis will be done to study its influence on model behaviour. The factors that influence the population growth rate, therefore, are outside the system boundary.

3.2 Assumptions

Since the Beijing private vehicle system is a very complicated system, we need to simplify the system and make some assumption to focus on the policy part. The assumptions made are as follows:

(1) The first assumption is that the needs for EVs by the consumers can always be met by the EV producers so that the production sector dosen’t need to be considered. The current situation is, the Beijing Government is making effort to encourage the use of EV, and the EV producers are also taking the first step to produce sufficient EVs, so our assumption is reasonable.

(2) The second assumption is that the price of CV is relatively stable since the CV industry is already mature; while the price of EV is fluctuant which is influenced by the relevant technology greatly.

(3) The third assumption is that citizens can not apply for a new conventional vehicle license plate (CVLP) and an electric vehicle license plate (ECLP) at the same time. This is actually the real situation in Beijing.

(4) The fourth assumption is that EV will not generate any pollution in Beijing. Even though the generation of electricity may cause pollution, it is far away from Beijing where is not populous.

(5) The last assumption is that people concerne much more about the price of CVs and EVs than about the use and maintenance cost due to the long-term uncertainty and inflation.

3.3 System dynamics model

Based on the qualitative analysis and assumptions above, we built an SD model with vensim software to show the Beijing private vehicle market. The model is shown in figure 2.

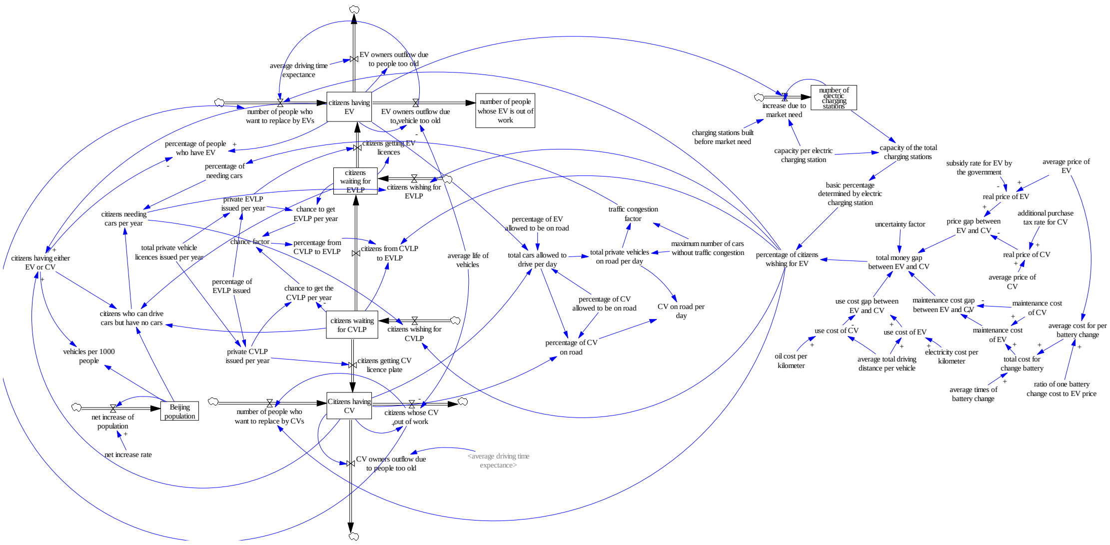

Fig.2 system dynamic model with vensim

4. Model specification

In this part, first, the major relationships between different factors in the model are explained; second, some major soft variables in the model are specified. These soft variables are not well-defined but are very important and influential on the model behaviour (Eric). Finally, we will give explanations for some important variables and functions.

4.1 Explanation about the model

From the model, we can see that the Beijing population will increase at a small growth rate, leading to the increase of population who need a vehicle. These people have two choices, either to buy EV or to buy CV. There are many factors that influence the people's choice. The fundamental factor is the number of charging stations, which determines the basic percentage of people who choose to buy EV. Another important factor is the total money gap between keeping a CV and an EV. The vehicle price, maintenance cost and use cost are considered to determine the total money.

When people have made their choice, they need to participate in the license plate lottery according to the current policy which is aimed to limit the license plates issued per year. Since there are so many people wanting to buy a vehicle, they have to wait for a relatively long time before they can get a license plate. It is worth mention that the lotteries for CVLP and for EVLP are separate, meaning that there are two queues for lottery. Further on, since the government is encouraging the purchase of EVs, the chance to get an EVLP is higher. Therefore, people may change their queue from CVLP lottery to EVLP lottery.

Besides the new buyers, owners whose vehicles are broken also need to replace the old vehicles with new ones. At this point, the assumption is made that EV owners can only choose to replace with EV while CV owners can choose to replace either by CV or by EV without lottery.

In terms of vehicle on road, it depends on the restriction policy by the government. The current policy is that only 80 percent of the vehicles can go on road per day, among which only CVs on road affects the air quality.

An important positive loop is between the charging stations and the EVs. The more EVs in use, the more charging stations will be built, and vice versa.

4.2 Major soft variables

Since there are many factors that should be taken into account, the relations between which are not well-known and completely logically determined, many soft variables exist in the model. The major soft variables are as follows:

(1) The first and most important soft variable is *"percentage of citizens wishing for EVs"*, because it is this variable that determines the development trend for both EV and CV. It is evident that the following variables "price gap between EV and CV", "maintenance cost gap between EV and CV"," use cost gap between EV and CV" and " number of electric charging stations" will have major influences on the variable "*percentage of citizens wishing for EVs*", but the exact quantitative relation between them is unknown. After a lot of literature study, the equation in the model is the optimal one we can come up with so far.

(2) The second one is *"citizens from CVLP to EVLP"*. Some citizens cannot wait to buy a CV because the chance to get a new CVLP is too low. This variable will be influenced by the chance factor which is determined by the chance to get a CVLP and the chance to get an EVLP.

(3) Other soft variables include *"price gap factor", "use cost gap factor", "*

maintenance cost factor", "basic percentage determined by electric charging station '', etc.

4.3 Other important functions and explanations of the variables

The other important functions or variables in the model are explained in table 1.

Table 1 some important variables

Variables	**Values or equations**	**Explanations**
Vehiclesper1000people	1000*total number of people who have a private car / total population	When the value is low, more public transport is needed
Percentage of citizens wishing for EV	Basic percentage determined by charging station*0.5^(total money gap between EV and CV/20000)	This percentage is determined by the money gap and number of charging station
Basic percentage determined by electric charging Station	capacity of the total chargingstations^0.5/10000	The relation between "basic percentage" and "capacity of total charging stations" is non-linear positive
Number of people who want to replace by CVs	citizens whose CV out of work*(1-percentage of citizens wishing for EV), 0.25, citizens whose CV out of work*(1-percentage of citizens wishing for EV)	CV owners choose to replace with a CV if they don't want EV after 0.25 year on average
Percentage from CVLP to EVLP due to chance factor	0.01* Ln (chance factor)	This function reflects the fact that when the chance factor is 1, the corresponding percentage is 0; and the relation is non-linear positive.
Total money gap between EV and CV	price gap between EV and CV +(maintenance cost gap between EV and CV + use cost gap between EV and CV)*uncertainty factor	Price, maintenance cost and use cost are considered in the total money gap
Percentage of Citizens wishing for EV	basic percentage determined by electric charging station* percentage due to money gap factor	
Chance factor	chance to get EVLP per year/chance to get the CVLP per year	The ratio between chance to get EVLP and chance to get CVLP

5. Model simulation and policy analysis

Based on the two base policies mentioned in the introduction and the specification above, the basic model is built and run to explore the plausible future under the current policy in 6.1. In 6.2 some new policies are introduced to improve the current situation. Due to the serious air pollution and terrible traffic, the attraction of the city Beijing has decreased sharply. In the basic model, the net population growth rate is assumed to be 0.

5.1 Plausible Future under the current policy

The following figures show the trend of important dependent variables in the coming 25 years. They are: number of CV/EV owners, percentage of people who have EVs, private vehicles on road per day, traffic congestion factor, percentage of citizens wishing for EVs, number of charging stations.

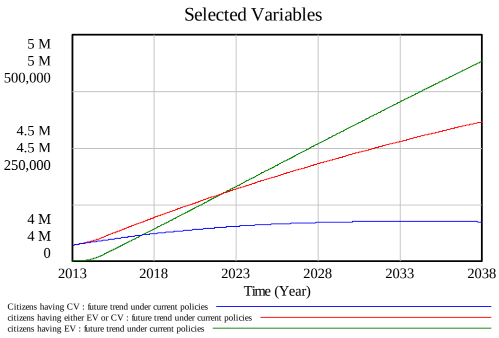

Fig. 5.1.1

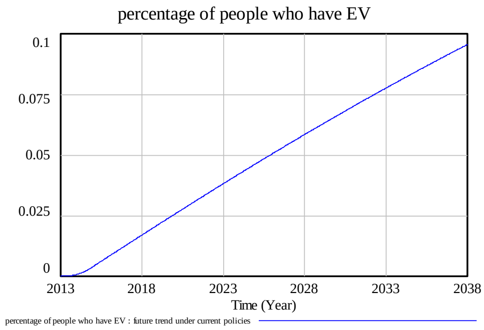

Fig. 5.1.2

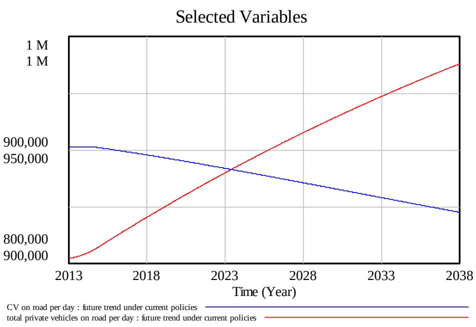

Fig 5.1.3

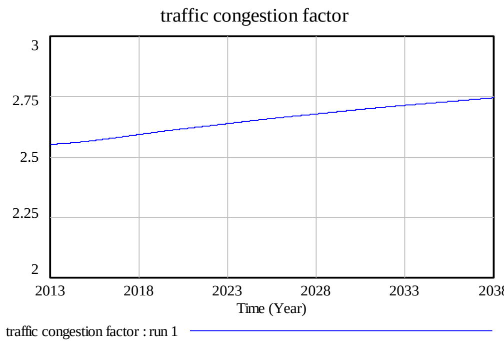

Fig 5.1.4

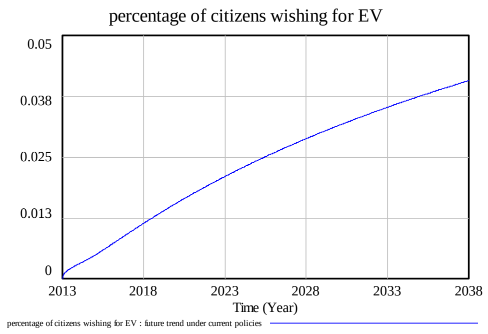

Fig 5.1.5

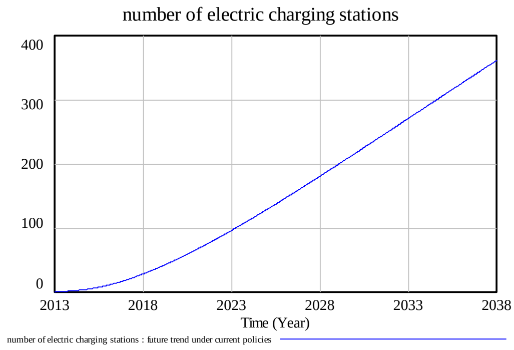

Fig 5.1.6

Fig 5.1.1 and Fig 5.1.2 show that the number of CV will increase at a very small rate, while the EV will increase fast and its proportion will grow from 0 to almost 0.1 in 25 years. Fig 5.1.3 and Fig 5.1.4 show that the CVs on road will decrease and the traffic congestion factor will increase slowly, but the total private vehicles will continue increasing. Fig 5.1.5 shows that the percentage of citizens wishing for EV will increase from 0 to 0.04. Fig 5.1.6 shows that number of charging stations will also increase a lot from 0 to around 370.

We can conclude that the current policies to restrict the private vehicles are useful. In the next part, we will explore the policies that can improve the current situation further.

5.2 Policy Analysis

In this part, some independent variables are changed to see what influence they have on the dependent variables. These independent variables include “number of license plates issued per year”, “the percentage of vehicles allowed on road”, *‘charging stations built before market needs’, ‘subsidy rate for EV by the government’, ‘additional purchase tax rate for CV’, ‘oil cost per kilometre’, ‘electricity cost per kilometre’.*

5.2.1 ‘Total private vehicle licenses issued per year’ and ‘percentage of EVLP issued’

The variable ‘total private vehicle licenses issued per year’ and ‘percentage of EVLP issued’ are studied to see how they will affect the trend of EV and CV.

Under the current policy, 132,000 new private license plates are issued per year, among which about 13% are for EV. The Fig 5.2.1 shows the number of private vehicles will increase or decrease about 0.25 million if the ‘total private vehicle licenses issued per year’ increases 10% or decreases 10%. The Fig 5.2.2 shows the percentage of people who have EV will almost double or nearly half if the ‘percentage of EVLP issued’ becomes double or half.

Therefore, the government can adjust the ‘total private vehicle licenses issued per year’ and ‘percentage of EVLP issued’ according to its expected goal and real situation to get a good result.

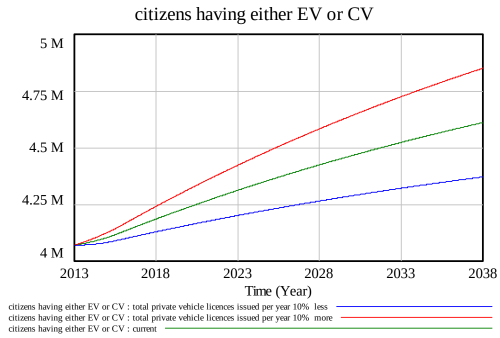

Fig 5.2.1

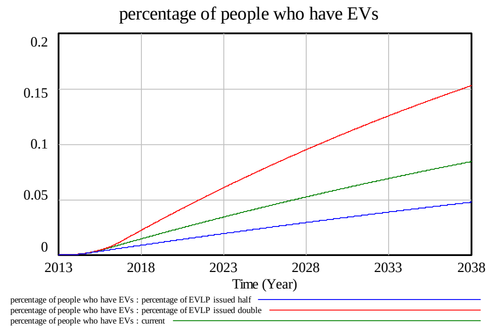

Fig 5.2.2

5.2.2 ‘Percentage of CV allowed to be on road’ and ‘percentage of EV allowed to be on road’

The variable ‘percentage of CV allowed to be on road’ and ‘percentage of EV allowed to be on road’ are studied in this part.Under the current policy, both 80% of CV and EV are allowed to be on road. Fig 5.2.3 shows the total private vehicles on road per day will increase about 10% if all CV and EV are allowed to be on road. Fig 5.2.4 shows the ‘CV on road per day’ will drop about 20% if all EV and 50% of CV are allowed to be on road.

Therefore, the Beijing government should adjust the ‘percentage of CV allowed to be on road’ and ‘percentage of EV allowed to be on road’ based on the level of traffic congestion and air pollution.

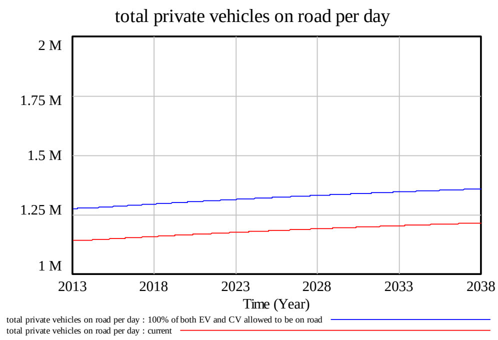

Fig 5.2.3

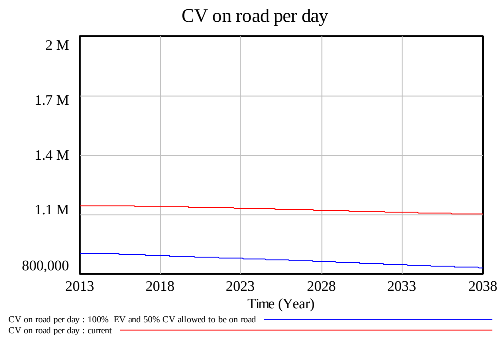

Fig 5.2.4

5.2.3 Other independent variables

According to the qualitative analysis, we know ‘charging stations built before market needs’, ‘subsidy rate for EV by the government’, ‘additional purchase tax rate for CV’, ‘oil cost per kilo meter’, ‘electricity cost per kilo meter’ will affect the ‘percentage of citizens wishing for EV’ and ‘percentage of people who have EV’. Model sensitivity is studied on these variables in this part.

(1) Fig 5.2.5 shows the difference between when there are 10 and 0 charging stations in the first 5 five years. When we see the first 10 years, there is a difference between them. The government should build some electric charging stations even before there are many EV. The availableness of electric charging stations will increase the competiveness of EV against CV.

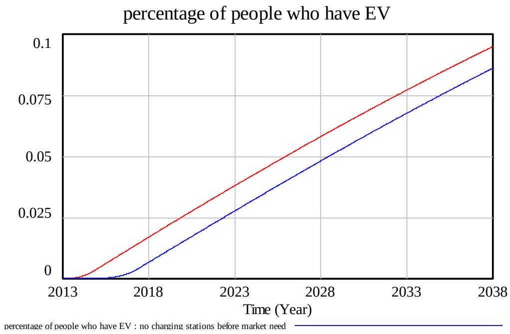

Fig 5.2.5

(2) Sensitiveness tests are shown in Fig 5.2.6 and 5.2.7, where the setting condition is that the subsidy rate fluctuates within the range 90% and 110% of the current subsidy rate. It turned out that the percentage of citizens wishing for EV is very sensitive to the subsidy rate. The 'percentage of people who have EV' is less sensitive to subsidy rate because license plate lottery policy plays a major role here. To make it in a more extreme case, when the subsidy rate is 0, Fig 5.2.8 shows that the 'percentage of people who have EV' will decrease by 40 percent compared to the current subsidy policy. Thus the subsidy for EV is extremely important for the development of EV.

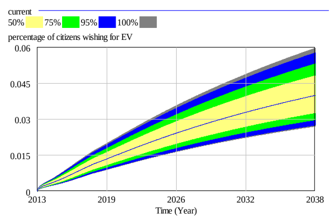

Fig 5.2.6

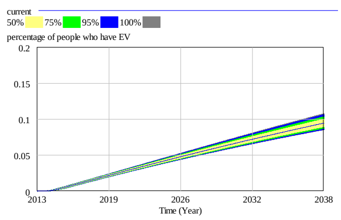

Fig 5.2.7

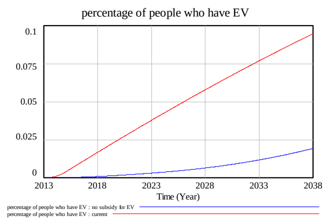

Fig 5.2.8

(3) We might charge additional tax on CV due to the air pollution caused by them to encourage citizens to choose EV instead of CV. The figure 5.2.9 and 5.2.10 show that the influence of the additional tax on CV on the 'percentage of citizens wishing for EV' and 'percentage of people who have EV'. It showed that the 'percentage of EV allowed to be on road' is more sensitive to the additional tax on CV than 'percentage of people who have EV' since the license plate lottery policy plays a major role for 'percentage of people who have EV'.

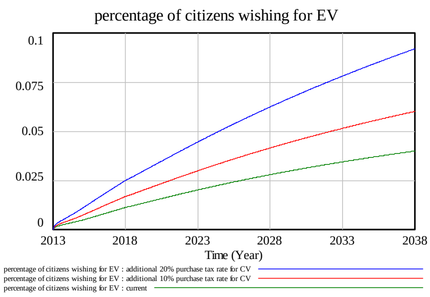

Fig 5.2.9

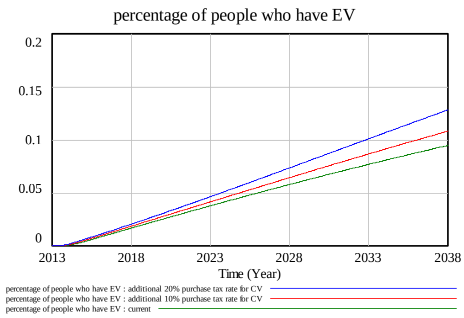

Fig 5.2.10

(4) Sensitiveness analysis is done on the 'oil cost per kilometer' and 'electricity cost

per kilometer' as shown in Fig 5.2.11& Fig 5.2.12 and Fig 5.2.13 & 5.2.14 respectively when they fluctuate within the range of 90% and 110% of current cost. The 'percentage of EV allowed to be on road' is more sensitive than 'percentage of people who have EV' to the factor 'oil cost per kilometer' and 'electricity cost per kilometer' because the license plate policy plays a major role for "percentage of people who have EV".

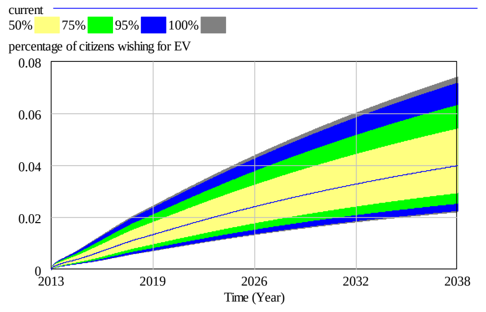

Fig 5.2.11

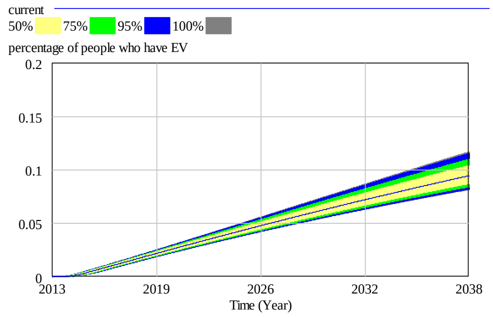

Fig 5.2.12

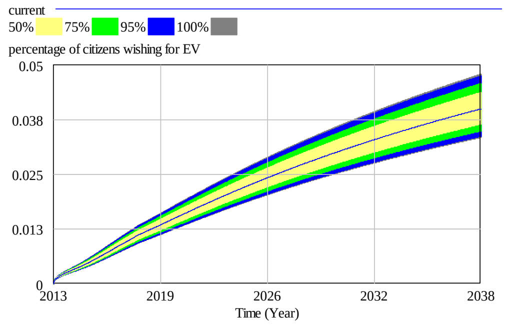

Fig 5.2.13

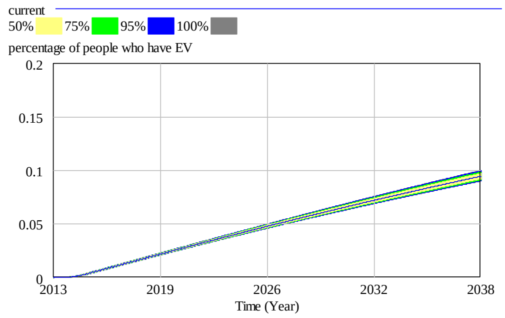

Fig 5.2.14

5.3 Scenario analysis

There is much uncertainty about the future. In this part, scenario analysis is done to explore plausible future of Beijing private vehicles, both of CVs and EVs. Scenarios are generated by setting different inputs for the model.

(1) The first scenario analysis is done by setting different inputs for the variable 'average price of EV. The average price of EV is influenced by the relevant technology about EV majorly. There might be great technology breakthrough in terms of EV in the near future and the average price of EV can drop greatly. It could also be that the in the next near future, no technology breakthrough can be achieved and the average price will not change much.

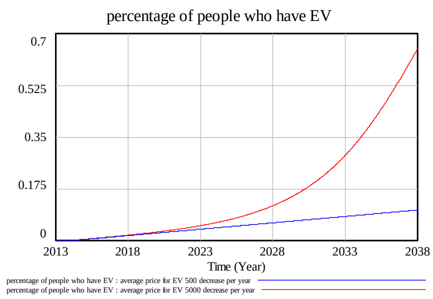

Fig 5.3.1

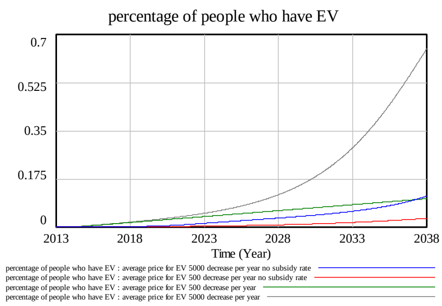

Fig 5.3.2

The Fig 5.3.1 and Fig 5.3.2 show that for the variable 'percentage of people who have EV', there is a large difference in terms of model behaviour in these two different scenarios. In the first scenario when the average price of EV will decrease 5000 RMB per year, the percentage of EV increases sharply. Even the subsidy rate decrease from 40% to 20%, the simulation result is still quite good according to the blue line in the figure. The conclusion about this scenario analysis is that the subsidy rate should be dependent on the average of EV. When the average price of EV is high, the government should provide a high subsidy for it.

(2) The oil price is also a very important factor in the model. There is some uncertainty about the oil price. It might stay stable in the next 25 years or increase a lot due to oil shortage or other political reasons. The figure 6.3.3 shows that in the scenario when the oil price increases to 1.5 RMB per kilometre, about 60% of the private vehicles will be EV. In this scenario, the government can lower the subsidy rate to some extent because the competitiveness of EV is big enough.

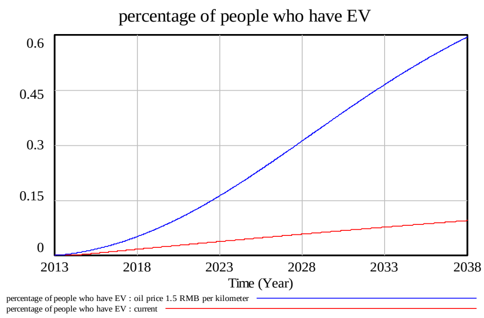

Fig 5.3.3

(3) Another interesting scenario is about the increase of Beijing population. Under the license plate lottery policy, the increase of the population has little influence on the number of total private vehicles since every a fixed number of license plates are issued independent of the population. However, this has great influence on the variable 'vehicles per 1000 people'. As shown in the figure 5.3.4, in the scenario when the population net increase rate is 0.01, the number of vehicles per 1000 people decreases from about 200 to 175. In this scenario, the government should invest more on public transport infrastructure. It is worth mention that without the license plate lottery, the number of total private vehicles will be affected by the population greatly.

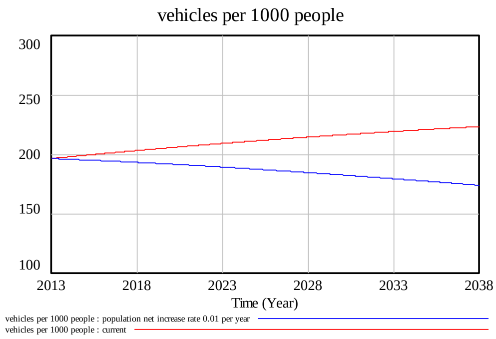

Fig 5.3.4

(4) There is hot debate on whether there should be restriction on EVLP or not. In the scenario when there is no restriction on EVLP, the total number of private vehicles (on road) will be larger while the percentage of EV on road will be smaller. Thus, there should be a trade-off between them. It might be suggested that in the first 10 years no restriction should be made on EVLP to encourage EV purchase. After that the restriction should be added as on CVLP.

The Fig 5.3.5 to Fig 5.3.8 show that if there is no restriction on EV, the total number of private vehicles will almost double and the total number of private vehicles on road will increase greatly in the future. The traffic congestion, therefore, will be much worse.

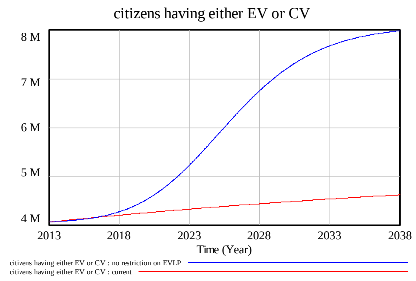

Fig 5.3.5

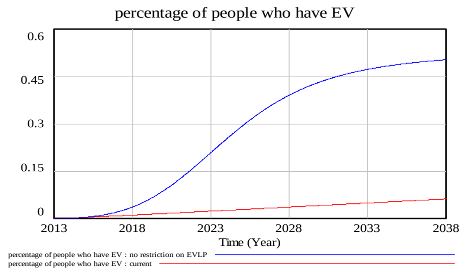

Fig 5.3.6

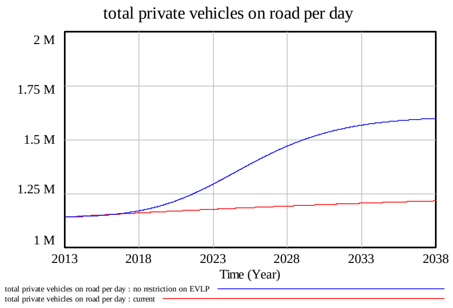

Fig 5.3.7

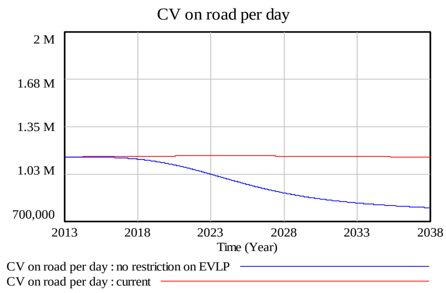

Fig 5.3.8

(5) Some citizens propose to adopt the auction policy for license plate as in Shanghai. Only if a fixed number of license plates are issued per year, it doesn't matter whether the lottery policy or the auction policy is adopted in term of total number of private vehicles. The advantage of lottery policy is the fairness for everyone. The advantage of auction policy lies in that those who need a private vehicle most and are willing to pay extra money for the license plates can get the license plates without waiting.

Thus a mix policy is proposed in this paper. The number of total license plates issued per year remains the same, half of which are assigned to those who join the lottery while the other half are distributed to those who participate in the auction. Therefore, potential vehicle buyers have the freedom to choose to participate in lottery or auction based on their situation.

It is worth mention that the government can get money in the implementation of the plate policy to cover the subsidy for EV as shown in Fig 5.3.9. However, the percentage of EV will be weakened under the mix policy compared to pure lottery policy as shown in Fig 5.3.10.

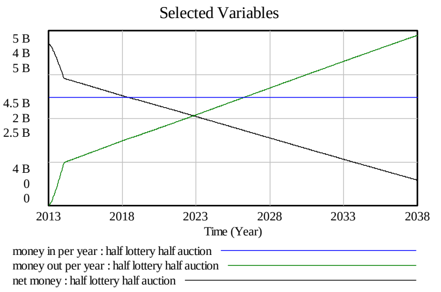

Fig 5.3.9

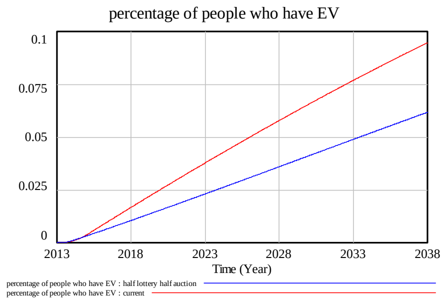

Fig 5.3.10

6. Reflection of the model

The model in this paper is a policy-exploration-oriented model. The model cannot represent reality. The trend of the model behaviour instead of exact quantity predictions of the future should be stressed. The trend of model behaviour can be used to study the implications of different policies.

7. Conclusion

The paper first analyzes the reasons why there are so many private vehicles in Beijing and why EV is not popular currently in China. Based on this analysis a causal diagram is drawn to explore the relations between many related factors. Both qualitative and quantitative analyses are conducted further to explore the plausible future about private vehicles in Beijing and the implications of different policies.

The model cannot be used to predict the exact vehicle number in the future. The behaviour trend, however, can be used for policy design. The following policies are recommended to the Beijing government to solve the current problems caused by the private vehicles.

• Policy 1: The government should build more **electric charging stations** before the demand for them. Lack of infrastructure is a major reason that discourages citizens from choosing EV.

• Policy 2: To encourage more EV buyers, the government should provide **subsidy to EV** buyers since the high EV prices another major reason that EV lacks competitiveness against CV. Furthermore, since oil and electricity price are another two important money factors. The Beijing government should adjust the subsidy rate for EV based on EV price, oil price, and electricity price altogether.

• Policy 3: To control the fast increase of private vehicles, there should be **restriction on new private vehicle license plates**. However, there will be more serious traffic congestion if the restriction is only on CV in the long run. A suggested policy design is that in the first 10 years, no restriction is on EVLP to increase the proportion of EV; then after 10 years, EVLP should also be restricted to control the increase the total number of vehicles.

• Policy 4: To control the total private vehicles on road per day, only some **percentage of vehicles are allowed to drive on a certain day**. The percentage of

CV allowed to be on road can be decreased gradually to reduce to control the air pollution.

• Policy 5: **A mix policy should be adopted to get the advantages of both lottery policy and auction policy**. Half of the new license plates are assigned to those who join the lottery while the other half are given to those who participate in the auction.

• Policy 6: With the restriction on new license plates, the increase of population has little influence on the total number of private vehicles. However, the variable ‘number of vehicles per 1000 people’ will decrease a lot in the scenario where the population increase greatly. In this scenario, the government should invest more on **public transport**.

All these policies can be mixed to achieve the expected percentage of EV and number of total vehicles.

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Appendix: Vensim model (big size)