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T1 ________________	**75517**	F1 ________________
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2018

Mathematical Contest in Modeling (MCM/ICM) Summary Sheet

Where are the Charging Stations?

Summary

In order to get the best national electric vehicle development plan, the optimal distribution of charging stations and devised a prediction for future electric vehicles usage.

We divided the interior of the country into two types, cities and rural areas. For the cities, because their traffic networks are developed, the charging station are mainly distributed along the road. So the mixed integer programming(MIP) model is established. For the countryside, the traffic networks are not nearly as robust as their urban counterparts. Charging stations can radiate to the surrounding areas which should be considered,thus the paper use Weighted Vorinor Diagram Model(WVDM) to analyze this aspect. For the charging stations in the city, the effect of the traffic flow is considered. At the same time, Queuing theory is introduced to calculate the average waiting time of the drivers. For the countryside, this paper also consider the building cost, and provide the calculation formula of the charging piles. Finally, a goal programming is set to solve the optimal distribution of the charging stations with the shortest waiting time and the minimum charge station cost.

In the model optimization section, we divide cities and villages by population distribution. This paper regards a small community in the city as a miniature village, so cities are simply a collection of villages. Within the small regional block we use WVDM to determine the specific distribution. The minimum spanning tree(MST) algorithm is used to determine the path of connected weighted point. The weighted point would be subclassified until it reached a threshold. After combining the two models, we use car flow to develop the optimized model into continuous time state based on GRA, which enable us to forecast future charger development.

Next, we do a sensitivity analysis of the model. The regression equations are built to analyze the relation between charging stations and EV transport share. We conclude that at the early stage the government should encourage consumers to buy electric cars. By simulation, when the two slopes are equal, the government should build charging piles, in support of the EV industry. The system dynamics model is also used to analyze the influence of policy subsidies on EV ownership. The effects of geographical shape, population and affluence on vehicle flow can be analyzed by regression equation Taking Australia as an example, we analyze the influence of topography on the distribution of local charging stations, then compared the site distribution with the distribution of simulated sites after the optimization of the previous models. Lastly, we also discussed the impact of new types of vehicles on the development of electric vehicles in the future.

Keywords: Electric Vehicle; Charging Station; Weighted Voronoi Diagram Model; mixed integer programming;

Contents

1 Introduction

1.1 Background

With the massive environment pollution and energy shortage, researches of electric vehicle (EV) are getting more and more attention. Using EV technology to boom the economy and reduce the waste have been a worldwide trend. However, the vehicle charging stations are crucial parts of the EVs' development. As of April 2014, 7,902 public charging stations existed across the United States[3].

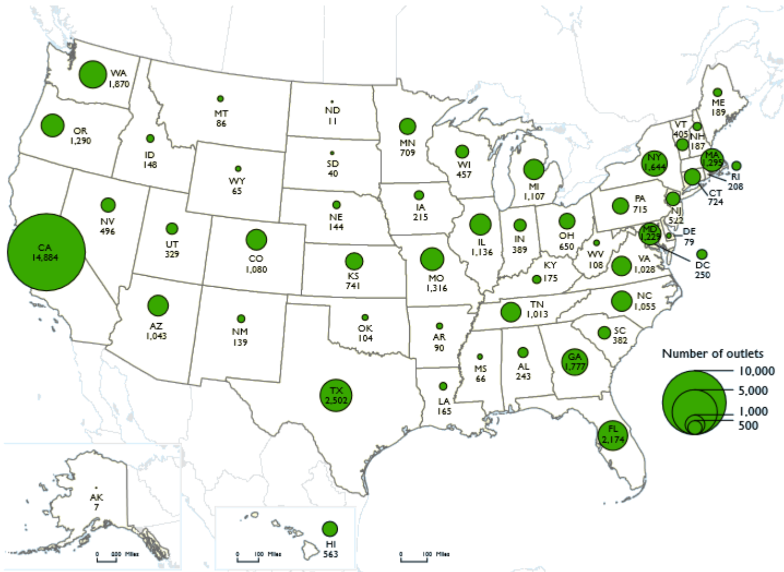


Figure 1: Electric Vehicle Refueling Stations by State: March 2017[7]

Tesla is one of the most famous EV company around the world. It has made significant progress even since January,2016, when the total number of Supercharger piles stood at 3,439, at 593 sites globally.[5]However, the infrastructure of the United Sates, especially the local EV station, is still inadequate.

1.2 Problem Restatement

The problems that we need to solve in this paper are:

- Tesla offers regular charging stations and supercharging stations. Based on the current and growing network of Tesla charging stations in the United States, you should evaluate whether Tesla can supply an all-electric for US. Estimate the number and distribution of charging stations that would be needed.
- Select one of the given nations (South Korea, Ireland, or Uruguay). Determine the number, placement and distribution of charging stations when it switch to all-EV. Give a suggestion on its invest strategy in charging piles. Consider the key factors that shaped your proposed charging station plan. Draw a timeline for the full evolution to EVs based on your growth plan.

- Take geographical factor, population density factor and wealth distributions into consideration during sensitivity analysis section. Discuss the feasibility of creating a classification system that would help a nation determine the general growth model.
- Take other technological impact in consideration, such as car-sharing, self-driving cars, rapid battery-swap stations, and even flying cars and a Hyperloop.
- Give a one-page handout written for leaders. Identify the key factors the leaders should consider for their own countries to develop a all-EV migrating plan.

The problem analysis can be briefly show as figure2

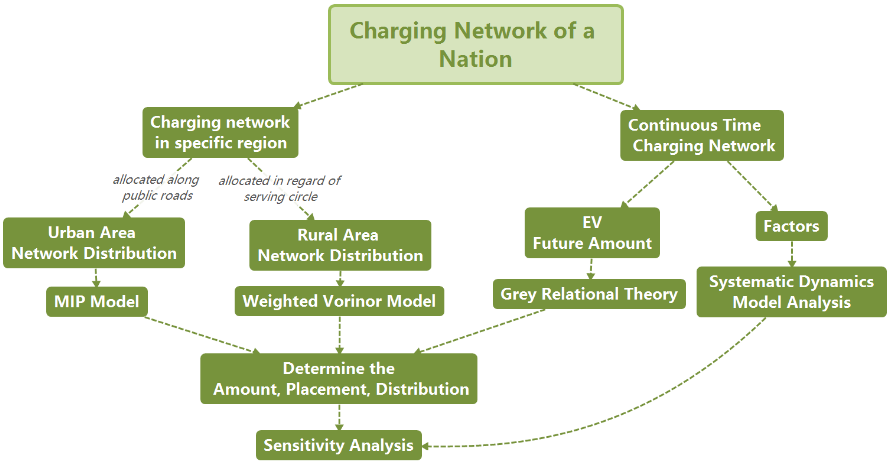


Figure 2: Problem analysis

1.3 Our Work

We use two models to solve the number, placement and distribution of the EV charging stations and charging piles respectively. In general, we use mixed integer programming(MIP) to define the number and distribution of charging stations in each state(We take the states as weighted dots). Then we use the same model to define the number and distribution of charging station in different cities(In this step we take the cities as weighted dots). We develop these submodels until the population at a specific area is less than 2500[11], when a region reach to that point, we consider it as a rural area or community.

To further present our work, we arrange our paper as follow. The figure 3 reflects our model developing method.

- In section 2, we give out the reliable assumptions to simplify the model.
- In section 3, 2 different models are established. They are constructed based on the type of region. We use a linear model which propose building charging stations beside highway to demonstrate the nation view. In rural areas and small community, we use Weighted Voronoi Diagram Model(WVDM) to find the approximate location and distribution of charging stations. We use these 2 models to simulate

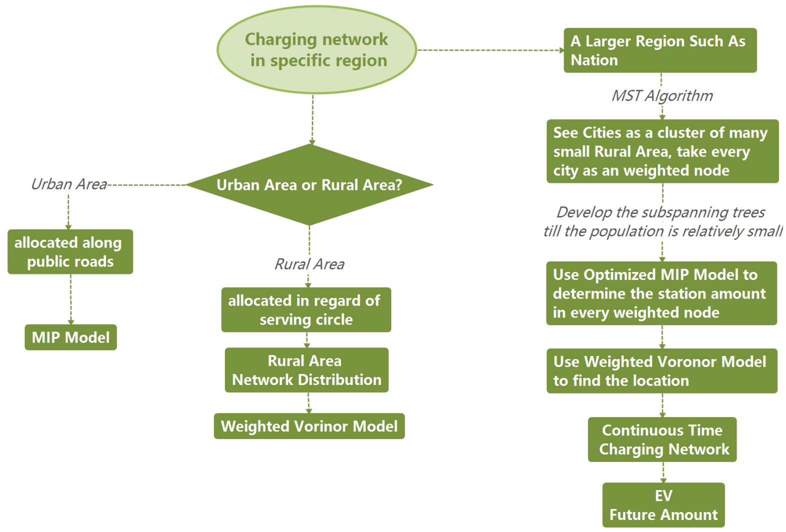


Figure 3: Model Developing Method

the car flow and to find out whether Tesla is ready to take United States into an all-EV era.

- In section 4, we build an optimized model to solve the previous problem shown in section 3, this time we consider a different layer of the country, not simply a composition of total public roads, but from states to cities, cities to districts, districts to communities. In this section, we develop the model in a continuous time, and take the building cost into consideration.
- In section 5, sensitivity analysis is given to show how the wealth, geographical factor, population density and new technical transport effect the model forecast

2 General Assumptions

- The data we found is authentic and reliable.
- EVs have to get recharge when the battery left less than 10%.
- Each EV will choose the shortest path to charging station.
- The growing speed of charging station amount is the same as charging piles'.
- The construction speed of Tesla charging station is equal to other brands.
- Charging stations have steady and unlimited power supply during operating hour.
- Every charging pile have the same serving ability. The serving ability of a charging station is the sum of its piles' serving ability.

3 Terminology

3.1 Terms

- **Grey relational analysis(GRA)**[15]
  It was developed by a Chinese Professor Julong Deng of Huazhong University of Science and Technology. GRA uses a specific concept of information. It defines situations with no information as black, and those with perfect information as white.

- **Voronoi Diagram**
  The Voronoi diagram in the plane is composed of many points, which can be regarded as each growth point in the point set R.And each growth element has to extends outward at the same expansion rate until it meets the other one growth point on the plane Graphics.

3.2 Symbol Description

In this section, we use some symbols for constructing the model as follows.

Table 1: Symbols Definition

Symbols	Definition
$\mathbf{i}$	a specific EV in a network
$\mathbf{I}$	a finite set of EVs in a network
$\mathbf{j}$	a candidate location for charging station
$\mathbf{J}$	a set of all candidate charging station locations
$\mathbf{A}(\mathbf{i})$	a set of i that are covered by j
$\mathbf{B}(\mathbf{j})$	a set of j that can cover i
γ	percentage of EVs over all cars
$\mathbf{f_q}$	traffic flow at q(j is on the path$q$)

P.s: Other symbol instructions will be given in the text.

4 Task1: Establish a Model

Urban areas have denser population and electric cars, while rural areas have less population, looser facilities and fewer EVs. Considering the enormous difference between these two, we set up 2 different models.

For urban areas, the charging stations are set along public roads. We use mathematical optimization and queuing theory to set up a quick and efficient charging network.

For rural areas, optimal electric power distribution networks are set up in regards of Weighted Voronoi Diagram Model(WVDM)

4.1 Local Assumption

- In the Urban area model, the charging stations are all supercharging station.
- In the Urban area model, the charging stations are only buildt along the roads in city. And we do not consider the beltways.

4.2 Urban Area Model Outline:a MIP formulation

As a charging station builder, our first aim is to allow all the EVs find a station wherever they are. Secondly, we tried to minimize the number of charging station that the EV have to get charged, because the cost is high. So our model is based on the assumption that an EV can find a station to recharge at anywhere if needed.

From the very beginning, we consider a specific road. First of all, we cut all the public road into many pieces. A fullcharged Tesla car can go 170 miles[8]. So every170 $\times (1 - 10\%) = 153$ miles should have a charging station. We put a candidate charging station point every 150 miles along the public road. Then we discuss whether candidate location is suitable to be selected.

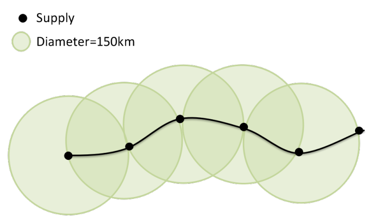


Figure 4: Stations Along a Road

The target problems which have to be solved in our model are:1)Decide whether the station should be build at the candidate location. 2)Which charging station should the customer choose to go. 3)Time for a customer to drive to a station and waiting in queue. 4)Capacity of the station. 5)The stations can satisfy the need for charging. 6)The demand point is uniformly distributed within the lane, while the demand of points are various.

Based on the the problem above, we set

Objective Function:

$$MinZ = \sum_{i \in I} \sum_{j} \in B(i) \tag{1}$$

Constraints:

$$\sum_{i \in A(i)} V_i y_{ij} \leq \sum_{j \in A(i)} E_j x_j \tag{2}$$

$$\sum_{j \in B(j)} y_{ij} \geq 1, \forall i \in I, \forall j \in B(j) \tag{3}$$

$$\sum_{i \in A(i)} x_j \geq 1, \forall i \in I \tag{4}$$

$$y_{ij} \leq x_j, \forall i \in I, j \in J \tag{5}$$

decision variables:

$$x_j = \begin{cases} 1 & charging\ station\ located\ at\ j \\ 0 & other \end{cases}$$

$$y_{ij} = \begin{cases} 1 & i\ distribute\ to\ j \\ 0 & other \end{cases}$$

In the proposed framework, the first two decision variables are determined using zero-one Programming, while other functions are inequality. So on the whole, the model is set as a mixed integer programming(MIP) formulation to determine the charging station location. In the following subsections, the optimization formulation of the single stage planning is outlined.

4.2.1 Supply-Satisfy constraint: Based on Queuing Theory

For the constraint(2) that stations should satisfy the need for charging, we have a formula to calculate the quantity demanded:

$$Vi = f_i \times \gamma \tag{6}$$

$$f_q = OD_{ij} = \sqrt{\frac{(w_i w_j)^3}{d_{ij}}} \tag{7}$$

The coefficient γ is a percentage of EVs of all vehicles on the path, it will change based on percentage of the whole country and fluctuate according to the geographical difference, population density and average GDP of the region. We set $f_q$is the flow volume on the shortest path between O-D pair q

The supply quantity:

$$E = U \times U_n \times \beta = \frac{W_s}{T_{operate}} \times U_n \times \beta \tag{8}$$

$W_s$is the average time that a customer stay in the charging station. $T_{operate}$ is the operate time of a station in a day. Charging process takes a long time, so from Queuing Theory $M/M/n$ using $Little formula$[13] have average waiting time:

$$W_s = L_s/\lambda = \frac{{\rho_1}^m P_0}{\mu m \cdot n!(1-\rho_0)^2} + \frac{1}{\mu} \tag{9}$$

Where n is the number of cars charging in station, m is the number of charging piles in a charging station. λ is the arrival density of the charging station.P_0 represent the average probability of cars are charging.

4.2.2 Other Constraint explanation

the function(3) states that every EV at the necessary point i that allocated to the supplying point$j$ can be charged successfully. Function(4) constraint that the charging station should be build at least one on the whole region. Function(5) describe the reality that EVs have larger number than the charging stations.

4.3 Rural Areas: Based on Weighted Voronoi Diagram

4.3.1 Scheme Optimization Model

When we plan to build a charging station, we must consider the cost of building a charging station. When planning the EV charging station, we considered the construction cost of the charging station and its operation and maintenance costs in the future. By comparing several solutions, we chose the least expensive solution as the final planning solution. Its objective function can be described as :

$$MinC = \sum_{I=1}^{N} C_{1i} + C_{2i} \tag{10}$$

Where costs include: construction investment costs, operation and maintenance costs required for one year, network loss costs, but here we only consider the annual investment costs and the cost of operation and maintenance.In the formula, N is the number of charging stations, C_{1I} is the one-year cost for the construction of charging station i, C_{2I} is the one-year cost of operation and maintenance of charging station i, C_{3I} is the one-year cost of the network loss of the charging station i, and C_{4I} is the one-year charging cost of the user within the service range of the charging station i.

The cost of building a charging station i for one year [14] is:

$$C_{1i} = (e_i a + m_i b + c_i)\frac{r_0(1+r_0)^z}{(1+r_0)^z - 1} \tag{11}$$

In the formula, e_i is the number of transformers configured in charging station i; a is the unit price of the transformer, m is the number of charging piles configured at charging station i; b is the unit price of the charger, i is the infrastructure cost of charging station i, B is the discount Rate, r_0 is the operating life

Charging station operation and maintenance costs mainly include the charging station equipment maintenance costs, equipment depreciation costs and staff salaries. We consider the annual operation and maintenance costs, which refer to the percentage of initial investment. If the scale factor is α, the annual operation and maintenance cost of charging station i is:

$$C_{2i} = (e_i a + m_i b + c_i)\alpha \tag{12}$$

4.3.2 The Location Selecting and Capacity Determined Model

The resulting V polygon area corresponds to the service area of the charging station. The choice of charging station location is within the respective V polygon area, similar to the substation location. In the V polygon area, in order to make the system more efficient, we calculate the minimum loss cost that all the EVs have spent to drive to the charging station from the starting place, and finally we use the sum of the calculation for charging Station location selection. That is, we use equation(11) as an objective function to select the location within each V polygon area.

When calculating the charging needs of EVs, we use the traffic flow at each intersection node to represent the traffic flow in the road network.Suppose that the number of links connected to intersection node l is w, the symbol l'_f is used to connect the l with the intersection node l, $f = 1, 2, 3, ..., w$; $p_i^f(l, l'_f)$represents the traffic flow density of the fth section of road junction node l connected to node l'_f at time t, so the traffic flow density of junction node j at time t follow the equation:

$$p_i^j = \sum_{l=1}^{w} p_i^f(l, l'_f) \tag{13}$$

As any section of the traffic flow are two-way, asymmetric, that is:

$$p_i^f(l, l'_f) \neq p_i^f(l'_f, l) \tag{14}$$

When calculating the traffic density of a node, we should set a uniform flow in the same direction, which means taking unified traffic flow into (or out) nodes.

During the time period T, charging needs of the junction node j:

$$p'_j = \int (l, l'_f) \neq_0^T p_i^l k_{ev} k_{cd} P_V dt \tag{15}$$

In the formula, k_{ev} is the ratio of the number of EVs to the total number of cars; k_{cd} is the ratio of the number of EVs that need to be charged to the total number of EVs, which means the charging rate of electric vehicles; and P_V is the average capacity of EV batteries.

If there are n intersection nodes within the service range of charging station i, we can give the formula for explaining the **charging requirement that charging station i needs to meet within T period**:

$$Q_i = \sum_{l=1}^{ni} q'_l \tag{16}$$

Thus **the number of charging piles in charging station i**:

$$m_i = 1 + [\frac{Q_{i(p+1)}}{PK_{xT_v} k_t}] \tag{17}$$

In the formula, m_i is the number of chargers needed to be configured in charging station i; p is the charging capacity margin of the charging station; P is the charging power of a single charger; k_x is the efficiency of the charger. *(The simulation result is shown in Section 4.4)*

4.3.3 General Idea

The planning strategy identified in this chapter is as follows:

We use the limits between maximum capacity of the charging station capacity S_{max} and the minimum of the charging station capacity S_{min} to estimate the minimum number of stations and the maximum number of stations in the planning area.

Set the loop variable N, for each N to find its optimal charging station location and capacity configuration. In this process, the initial location selection using coordinate geometry method to achieve;

Obtain the charging station service area of the division through the weighted Voronoi diagram to automatically;

Within each service partition (we obtain the V-shaped curve by partitioning the s-pace of weighted Voronoi diagram), the location of the EV loss in the charging path is minimized.

Through repeatedly calculating , adjusting the coverage of subareas and the location of the charging station, we can obtain the optimal planning scheme for each charging station of the electric vehicle corresponding to each N .

Then, the program $N_{max} - N_{min} + 1$ is sorted according to the total social cost

Select the planning of the smallest total cost of the community planning area as the final planning of electric vehicle charging station.

Estimated number of charging stations

We estimate the range of charging stations, using the total charging demand Q in the planning area, the minimum capacity limit S_{min} and maximum capacity limit S_{max} of the charging station. The planning area charging station number range is: $N_{min} < N < N_{max}$, in which:

$$N_{min} = 1 + [\frac{Q}{S_{max}}] \tag{18}$$

$$N_{max} = 1 + [\frac{Q}{S_{min}}] \tag{19}$$

4.4 Simulation: Tesla Charging Stations Serve all the corner of United States

Now we start considering how many charging stations are United States needed for all-EV era. If that era is coming, the charging stations should be within drivers' reach, that is, the serving circle of charging station should cover all the roads in United States. In order to solve the expected station amount around United States, we have to figure out the total length of public roads[5], and EV accounted for the proportion of all vehicles.

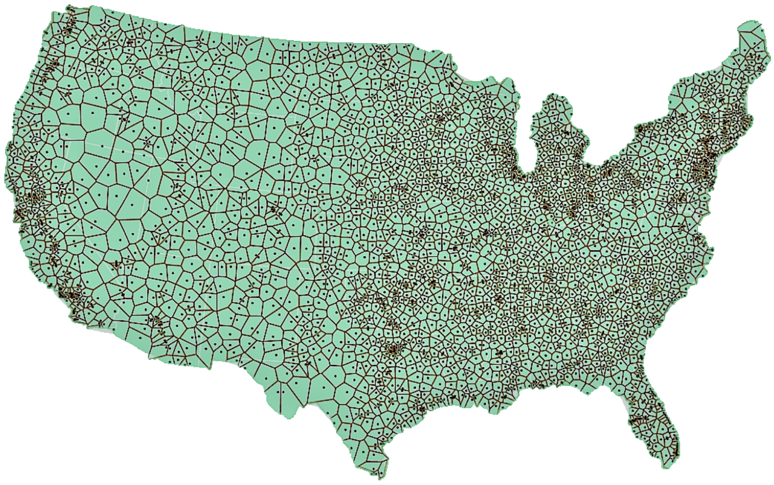
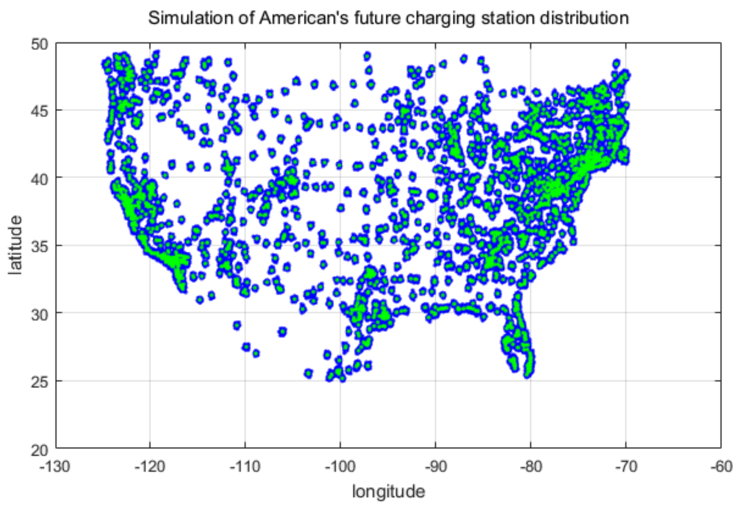


Figure 5: Simulation Based on WVDM

Total number charging station is needed in United States in all-EV time

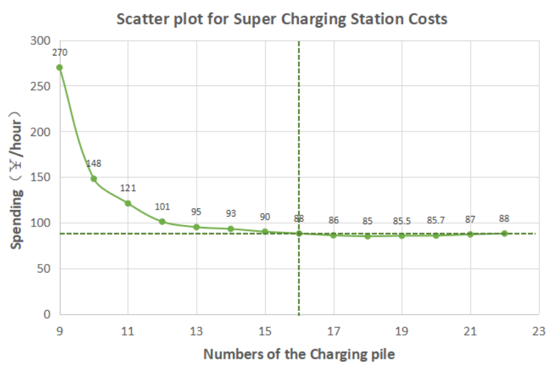
United States now have approximately 4400 Tesla super charging station and regular charging station[8]. Around mid2016, United States have 44000 charging station on total[20] Around mid2016, United States have 44000 charging station on total[20]. In November,2016, Tesla holds 18.2% of all the charging stations in United States. Assuming the growing speed of every charging station brand is same, we figure out at least 483929 charging stations are needed when US achieve all-EV. So now Tesla is not able to realize its all-EV US dream.

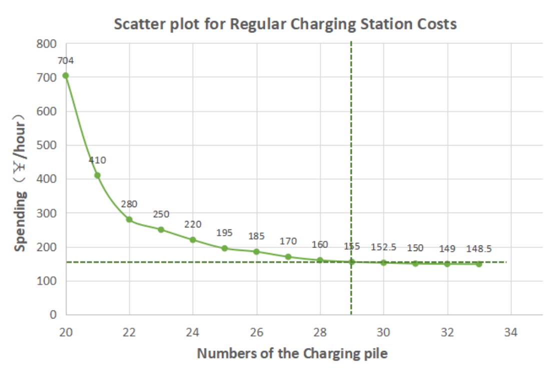


Estimated number of charging piles in each station

An EV takes 30 minutes for super charging, and 3 hours to 8 hours for regular charging[19]. The cost of super charging pile is between 1746 dollars and 5717 dollars, and the cost of regular charging pile is 222 dollars to 492 dollars. Accordingly, we set the charging rate of super and regular charging piles to 3 and 0.3 respectively. At the same time, the cost of super and regular charging piles is 4526 dollars and 397 dollars respectively, the cost of transformer is 3494 dollars, the discount rate is 0.096, and the operation life of equipment is 10 years.

Then combined with the data of the charging station electric vehicle users, the optimization results are solved by using the MATLAB program.





The result is as follows: through observation curve, we get that the optimal number of fast charging piles is 16, and of optimal stations of slow charging piles is 29. Fortunately, after increasing the optimal number of charging piles, the cost of charging stations will not decrease again.

5 Model Optimization

5.1 A General Method

In the previous model, the method divides different regions into cities and villages. However, in practical application, the demarcation line between urban and rural areas is blurred, and when analyzing the charging network plan of the whole country, this kind of classification model is difficult to apply. We start with the essence of the city and the country: What is the main difference between them? The answer is the population. We can put the city as a collection of many small villages, and in reality, a community in the charging station distribution of city and village, they are not built along the road, but to divide the area in serving polygons. **So we develop a classification method, which the cities are divided into many small rural areas**. in the countryside with The aforementioned WVDM to solve The problem of The specific number and distribution. Therefore, our thoughts are mainly divided into the following steps:

1. We regard states as weighted points from the national view. And then use a method of the shortest path to link them together. The distribution of the states will become a tree structure. We regarded the states as candidate station nodes.

2. Further, we are going to a state view. There is a lot of cities within the state. And we are going to transform it into a tree structure and analyze it at the national level. This layer analyzes the nodes of the tree structure until the population within a node reaches the set threshold.

3. Once the population is below the set threshold, the population is small, we can use WVT to solve its distribution.

So we have combined the two previous models. In this way, we can see the distribution of different parts of the country, instead of dividing cities and villages by political idea. It also solves the rural and urban classification problem. On this basis, we add dynamic factors into the original model, and we can use the previous data to predict the number and distribution of charging piles at a certain point in the future.

5.2 Optimization Overview:Expand the Charging Network Based on FRLM

In the previous model, we assume charging stations should cover all the roads, however, if we want to start it from zero, the objective function should appear as maximized. The flow refueling location model (FRLM) was developed to minimize the investment necessary to create a refueling infrastructure by optimizing the location of fueling stations. The original FRLM assumes that the presence of a refueling station is sufficient to serve all flows passing through a node, regardless of their volume.

the formulation of the FRLM is as follows:

$$MaxZ = \sum_{1 \in Q} f_q y_q \tag{20}$$

constrains:

$$\sum_{h \in H} V_h \geq y_q, \forall q \in Q \tag{21}$$

$$x_k \geq v_h, \forall h \in H; k \mid a_{hk} = 1 \tag{22}$$

$$\sum_{k \in K} x_k = p \tag{23}$$

$$x_k, v_h, y_q \in \{0, 1\}, \forall k, h, q \tag{24}$$

In the optimized model, we mainly made 3 improvement:

- **objective function appears as maximized**
  Based on our previous model, we change the objective function into seeking for serving the maximum amount of EV while remain the number of charging station limited. This kind of switch can better suitable for the region that is taking a very first step of all-EV project and lacks of fund.

- **EV are able to refuel half-full at a certain charging station**
  In reality, sometimes the queue is too long for waiting, so people may charge their car to half-full, which enable them to drive to next charging station to refuel. We add this situation by introducing maximal covering location model(FCLM)[11] method, that is, considering the car flows on the whole path rather than a specific point. We made a large improvement: redefine the facility location variable as an integer variable rather than a binary variable, so it is possible for a node to have more flow than a single facility can refuel.

- **Each station can have more than one charging pile**
  We use x_k instead of x_j, which k defines the number of pipes in a charging station. Beside some busy urban main streets, more piles will be needed in a charging station.

- **better constraints**
  we use y_{qh} instead of y_{ij}, firstly that is not a single demand node to a single supply node; secondly it ensures that no station refuels more than its capacity, the optimized model requires precise knowledge of where each flow refuels. We uses y_{qh} to indicate exactly which combination of facilities h is refueling the flow.

The formulation is as follows.

Objective Function:

$$MaxZ = \sum_{q \in Q} \sum_{h|b_{qh}=1} f_q y_{qh} \tag{25}$$

Constricts:

$$\sum_{q \in Q} \sum_{h|b_{qh=1}} \Gamma f_q y_{qh} \leq S x_k, \forall k \in K \tag{26}$$

$$\sum_{k \in K} x_k = p \tag{27}$$

$$\sum_{h|b_{qh}=1} y_{qh} \leq 1, \forall q \in Q \tag{28}$$

$$y_{qh} \geq 0, \forall q \in Q, h \in H \tag{29}$$

$$x_k \in N_+ \tag{30}$$

5.2.1 Detail Description

The objective function (16) seeks to maximize the flow volume that can be charged. The car flow f_q for O-D pair q is multiplied by the proportion of the flow y_{qh} that combination h can recharged, summed over all flows and all combinations of charging station.Constraint (17) is a multipurpose constraint. Constraint (17) looks like directly copying from previous model, but Γ the percentage of EV of all vehicles on the path here is a forecast of future proportion of EV and all vehicles. Here we use Grey relational analysis(GRA)

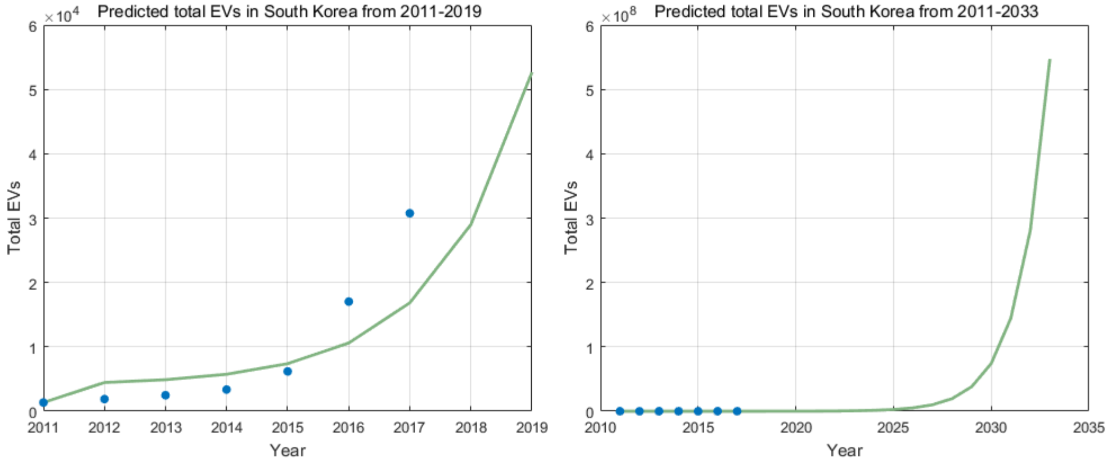
5.3 Continuous Time Model: Grey relational analysis(GRA)

We collected the national EV ownership data for South Korea from 2011 to 2017. According to the Grey relational analysis(GRA)[17], we obtain a variable sequence prediction and first-order differential model $GM(1, 1)$ for predicting time series prediction curve of Korean national ownership of EVs. The implementation of the program is written in MATLAB. $GM(1, 1)$ algorith can realize the GRA.

Table 2: Grey prediction accuracy registration form

Year	2011	2012	2013	2014	2015	2016	2017
EV Amount	1000	1800	3000	5000	8000	15000	20000

Based on the data above, we get the estimation of electric vehicle ownership in South Korea based on $GM(1,1)$ algorithm. The results and accuracy parameters are as follows:



Accuracy parameter	Number
Mean of error	0.14
maximum error	0.49
Minimum error	0
Standard value of error	0.89

Figure 6: Error Analysis

Comparing the calculated accuracy parameters with the standard table, we know that the error is relatively small, so the predicted curve is reliable.

Electric vehicle proportion forecast:

According to the data, at present, there are 20 million cars in the South Korea. We assume that the total volume of cars does not change. Combined with the prediction curve calculated, we get the conclusion.

Year (year)	The total number of cars (ten thousand)	Electric vehicle total (ten thousand)	proportion
2028	2000	200	10%
2029	2000	600	30%
2031	2000	1000	50%
2033	2000	2000	100%

Figure 7: Electric Vehicle Proportion Forecast

Car growth model

The development of electric vehicles is a complex system, which has been subjected to various economies, technology, policy, infrastructure, environmental pressure and so on. In this section, the system dynamics[17] applied to the EV scale of deduction. We puts forward a EV scale deduction method based on system dynamics, analysis of various factors and their relations. We establish a system dynamics model, through simulation.

We mainly consider the policy modules of the EV scale forecasting system. In the policy section, we mainly consider the influence of the state on the purchase subsidy of the EV. We constructed the specific functional relationship between the variables under each module, expressed it by stock flow, and modeled each module through the system dynamics software Vensim.

Policy module

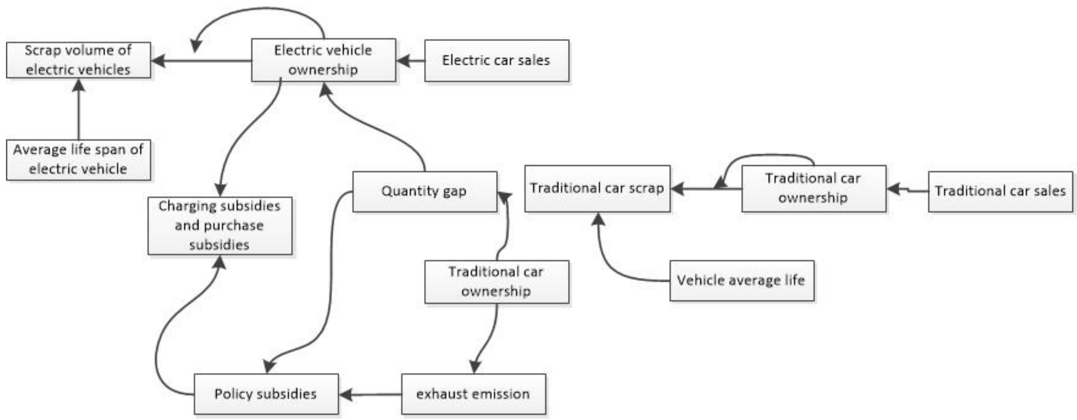


Figure 8: Policy Module Stock Flow

The specific formula and the main equation are as follows:

$$D_{QN}(t) = CV_{parc}(t) - EV_{parc}(t) \tag{31}$$
$$PS(t) = D_{QN}(t) \times \varepsilon_2 + CE(t) \cdot \varepsilon_3 \tag{32}$$
$$CE(t) = CV_{parc}(t) \times \varepsilon_4 \tag{33}$$
$$CS(t) = PS(t) \times CE(t) \times \varepsilon_5 \tag{34}$$
$$MP(t) = con_2 \times e^{-(t/\varepsilon_6)} \tag{35}$$

$D_{QN}(t)$is the difference between the number of EV and CV, and its difference value and carbon dioxide emissions $CE(t)$ jointly determine the size of the policy support of $PS(t)$. $\varepsilon 2$ and $\varepsilon 3$ are the difference and carbon emission factors of EV and CV, and the $\varepsilon 4$ is the traditional vehicle emission factor. $\varepsilon 5$ is a charge subsidy factor, and ęÁ6 is the purchase subsidy factor. $CS(t)$ is a charge subsidy; $MP(t)$ purchases subsidies, con_2 is the initial value of the subsidy.

5.3.1 Growing plan

In our model, there is no clear distinction between urban areas and rural areas. But cities tend to have more people, thus it needs more classification process than a village of the same size, which may reach to set threshold(to switch to WVDM) easily. Further more, both the optimized MIP model and WVDM have a close relationship with population density, which can affect the car flows and further affect the distribution of charging stations. More charging stations are needed in cities, while villages need fewer stations.

5.4 Simulation and Analysis

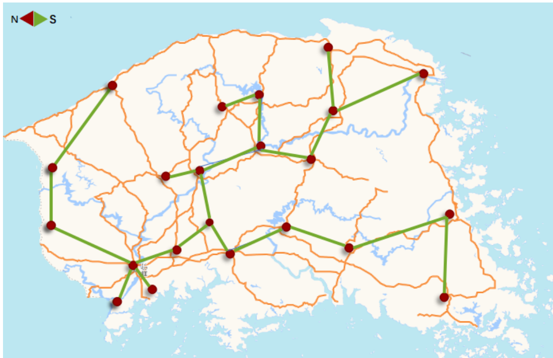


Figure 9: Link the State Using MST Algorithm

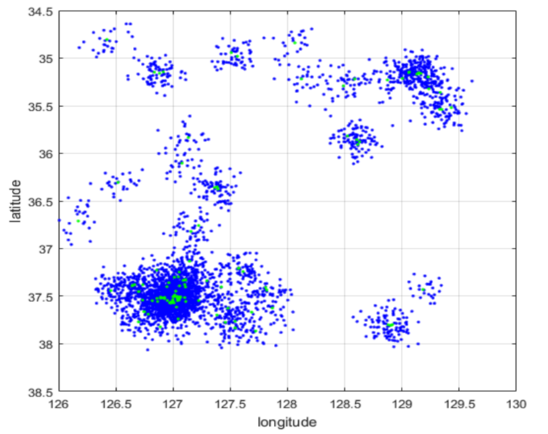


Figure 10: Simulation results

Today, the typical driving range for all-electric vehicles is 60 to 120 miles[16].By using python language to collect the statistics from Tesla website[8], till 2018 February, South Korea has 134 Tesla supercharging station and regular charging station. By the end of 2017, South Korea will have 1450 charging station[21]. We assume all charging station companies build new stations at same speed. With the help of MATLAB, we believe that 30240 charging stations are needed for all-EV era.

We get the basic data of the region by querying the Korean data statistics yearbook, as shown in Table 4. The region can represent a more developed economy, a large scale of cars and a high volume of cars for lots of people. We use Vensim software to estimate the stock flow relationship and regional EV development.

Table 3: Parameter Setting

parameter	Initial Value
Population/people	5125
GDP/trillion dollars	1.411
CV scale/10000	1998.5
EV scale/10000	1.5
EV average purchase allowance/$10000	1.07
CV average price/$10000	1.332
EV average price/$10000	3.512

We simulate the influence of the government's different subsidies to electric vehicles on the purchase rate of electric vehicles.

subsidy	The initial value of the purchase allowance	Purchase subsidy factor	Quantity difference facto	Carbon emission factor
High	55000	0.99	0.0025	0.4
Medium	35000	0.98	0.0015	0.3
Low	15000	0.95	0.0010	0.2

Figure 11: Different Subsidy Scenarios

The trend of EV purchase rate under different subsidy policies. All the different schemes show the trend of rapid growth after the first slow growth. The initial value of subsidies for the purchase of different EV to buy a share of the initial value is different because of the different subsidy policy. High subsidies under the EV can get better development in the early stage. Behind three subsidies scene, EV growth rate is basically the same, indicating that the state subsidies have an crucial effect on the popularity of electric cars. Therefore, we concluded that the main factor affecting the growth plan of electric vehicles is the subsidy from the beginning. The greater the degree of national support, the faster the electric vehicle will grow to 100%.

6 Sensitivity Analysis

6.1 How the Costumers and Charging Stations Effect Each Other

We collected South Korea 2011 national EV ownership data by 2018 and the construction of charging pile facilities in Korea from 2011 to 2018, and conduct further analysis on the data.

According to the data we collected, two impact models are set. Model 1 takes the EV possession as the independent variable, the charging piles as the dependent variable, the model 2 the charging piles as the independent variable, the EV possession as the dependent variable. In our opinion, the slope of the influence curve can reflect the influence of the independent variable on the dependent variable, that is, the influence of large slope is large and the effect of small slope is small. We use MATLAB to get the curve after

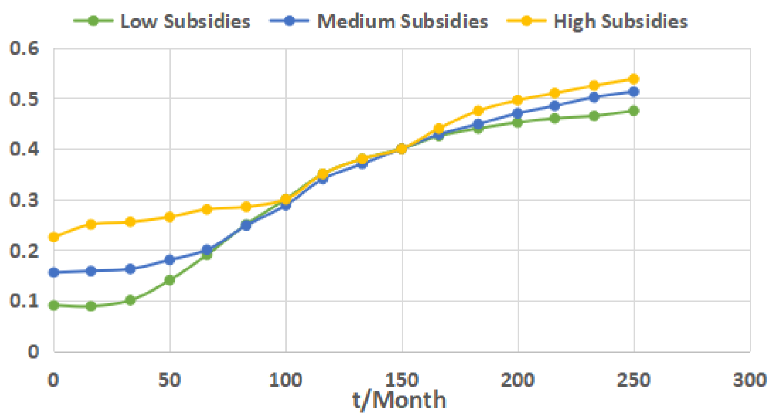
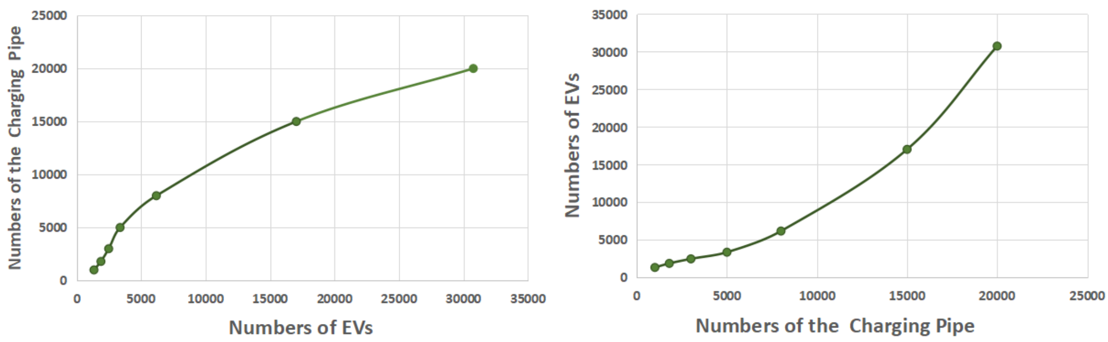


Figure 12: Simulation results

fitting.



From the analysis of the curves, we can see that the slope of the influence curve of model one starts from the beginning, and gradually decreases to the back; the slope of the influence curve of model two is relatively small from the beginning, but it grows larger behind. This shows that the ownership of EV has a relatively large impact at the outset, and the impact of charging piles is greater behind. Considering that the well-established charging pile facilities require a large amount of capital in the beginning, which will cause a heavy financial burden on the state, we think from the outset, it is reasonable to promote the scheme for consumers to buy electric vehicles and then build charging pile facilities. Finally, we come to the conclusion that consumers should mainly promote the purchase of EV from the very beginning. After a certain period of time, the state will then devote its major efforts to building well-equipped charging station facilities so that the use of electric vehicles and their convenience can be better spread.

6.2 Model Adjusted to Different Regions

Three main influence factors: **wealth gap**, **geographical location**, **population density**.

In Jia Wenrui's research[18], various data is collected, and a regression equation of traffic flow and GDP for a region is shown:

$$y = -8981.573 + 0.369x \tag{36}$$

Where y is the traffic flow and x is the GDP of an area.

We believe that all three of them ultimately affect the traffic flow, and the literature can have a linear relationship with the traffic flow.

Three influencing factors are given respectively: wealth gap w, geographical location θ, population density c.

Set a general impact factor r, $r = w + \theta + c$, the traffic $f = r \cdot f_i$ (f real for road traffic, f_i basic capacity of homogeneous cases road), specific analysis for each region, we select each region the main influence factors (from the above three factors) and its main discussion, the other two think even, do not change.

Original charging station development plan: a country in its internal the conditions of balanced development of all regions, charging stations distribution between urban and rural areas according to the proportion of the previous asked to calculate distribution. At the same time, each region has subsidy policy to encourage consumers to buy a car, while to invest the construction of the charging station later.

We analyze in Australia, for example, according to the original we proposed charging station development plan, each part of the Australian charging stations should be evenly distributed.

Australia has dry climate in central part, while warm and humid climate on the coast, where mainly in the plains. That demonstrate a massive change in a, while c and b remain stable. This results in bigger traffic f along coast. Charging stations are mainly distributed in areas near the sea.

Conclusion

Original charging station development plan is only applicable to regional uniform inside the country, but not applicable for regional uneven areas inside the country, different countries under different conditions should have different development plans. Countries with large geographical differences in different regions should mainly consider the impact of geographical factors on the distribution of charging piles (e.g. Australia).Similarly, countries with uneven population distribution should consider the impact of population density(e.g. Singapore). Similarly, countries with uneven population distribution should mainly consider the impact of population density, while countries with a large gap between rich and poor should consider the impact of regional GDP on traffic flow and thus on charging pile network(e.g. China).

6.3 Influence of Other New Energy Source

With the shared car, self-driving, the development of new technology station to replace the battery, electric car facilities and the development environment will become better, we think it will improve people's willingness to buy EV, to reflect the system dynamic model we established, we think it will make the model factor alpha decrease. For the changed model, we re-emulation and get the sensitivity analyze curve(SAC), By

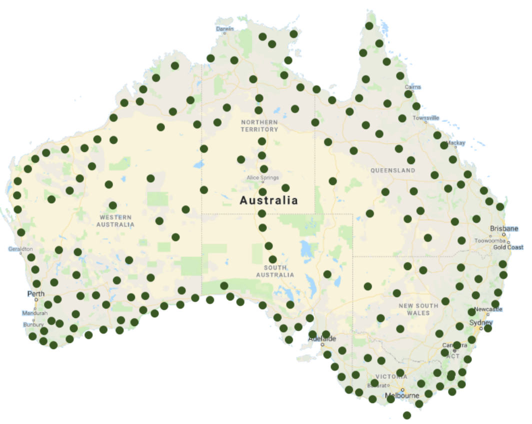


Figure 13: Australia's Future charging station based on Optimized model

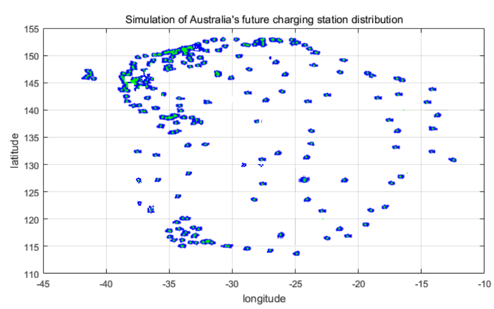


Figure 14: Simulation of Australia's Future Charging Station Distribution

comparing the curves before and after, the slopes of each curve increase, and the starting point also improves. This means that the growth rate of electric vehicles increases and the market share of electric vehicles increases. We conclude that the development of the new technology can improve the market share of electric vehicles and increase the rate of growth.

7 Strengths and weakness

7.1 Strengths

Our model effectively achieves all of the goals we set initially. It is fast and can handle large quantities data of variables effect charging stations' amount and placement, but also have the flexibility we desired. Though we did not test all kinds of situation and all the countries' charging station network, we showed that our model optimizes state districts for any of a number of variables.Our model can describe the continuous charging network base on the EV development state, building cost, population and wealth of a specific region. It has wide range of application and good time applicability. As well, our method is robust.

7.2 Weakness

Weakness of the model included assumptions made for simplicity that likely do not hold. And some special data can't be found, such as the electric vehicle at its initial stage are lacks relevant data support.

8 Handout

Electric cars are welcome because of their environment friendliness, and all countries are making positive progress. For the popularization of electric vehicles, we found that the country needs to fully consider the construction of charging networks and the future growth forecast of electric vehicles. Charging network construction needs to consider the coverage and user convenience, while the proportion of electric vehicles need to consider the policy subsidy factor.

For the charging network coverage, to achieve the maximum coverage of the charging network, the key factor is to determine the optimal distribution of charging stations in urban and rural areas; the convenience of charging network that is the average waiting time for charging users to achieve the minimum average user waiting time , The key factor is to determine the optimal number of charging pile charging station allocation.

According to the growth projections of the country's electric vehicles in the future, we found that the higher the policy subsidies has from the outset, the higher the initial proportion of electric vehicles has and the faster the popularization of electric vehicles is. At the same time, we also found the development of technologies such as shared cars and battery replacement stations have raised the popularity of charging cars.

The suggestions we put forward above mainly focus on the situation of even development in different regions of the country. In practice, the optimal distribution of charging networks will be affected due to the differences among different countries, such as the geographical factors, the gap between rich and poor, and the population density. For different geographical factors, for instance, Australia's coastal plains and sandy central area, we can get more distribution stations along the coast, while fewer in central. Similarly, you can also consider the impact of the difference between the rich and the poor and the difference in population density.

All in all, the development plan of national electric vehicles needs to fully consider two essential factors, which are national charging network construction and the domestic electric vehicles growing forecast. Charging station network needs to take the geographical factors, the gap between rich and poor, and the difference in population density into consideration. In addition, the growth forecast and popularization of electric vehicles need to take full account of the positive impact of subsidies from national policies and other corresponding technologies.

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