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2018
MCM/ICM
Summary Sheet

The Electric Vehicle Age

Summary

In recent years, carbon dioxide emissions caused by the global warming, energy shortages and environmental problems have become the focus of world attention. As a result, many governments are promoting electric vehicles. However, many complex problem remained to be solved. Here, we will discuss optimal numbers of charging stations and the strategy to develop charging station net under different circumstances.

First, we establish a **queuing model** to simulate the process of electric vehicles entering a charging station. By reasonable assumption and data from U.S. Census Bureau and U.S. Bureau of Economic Analysis (BEA), we estimate the charging points and stations needed in America.

Second, we establish a **distribution model** based on the demand which is affected by **population density distributions**, **economic level** and **the quantity of electric vehicles in certain region**. We apply this model to Ireland and get the optimal numbers and distribution of charging stations in Ireland. Then we put forward a strategy to help Ireland build charging stations from zero chargers to a full electric vehicle system and estimate how the popularity of electric vehicles changes with the time.

Third, we apply our model to analyze how should different countries should develop their own electric vehicle system under different circumstances, of course, with some experience.

And then we simply discuss the impact on the development of electric vehicles brought by new technologies like flying car, self-driving and so on. Lastly, we point out the strengths and weaknesses of our model and analysis.

The handout for the leaders of a wide range of countries who are attending an international energy summit is given at the end of the essay.

Keywords: electric vehicles; queuing model; distribution model; Ireland; new technology

Contents

1 Overview

1.1 Background

Nowadays, environmental and resource problem has become one of the most serious problem that limits the development of many countries. Out of economic and energy reasons, governments around the world, especially in developed countries, has been making efforts to promote the popularity of electric vehicles. However, complicated factors stuns the promotion of electric vehicles, one of which is the lack of charging stations. Here, we will discuss the optimal number, placement, and distribution of charging stations in some countries. Also, we will discuss how other factors like technology would effect the development of electric vehicles.

Figure 1: A charging electric vehicle

1.2 Restatement of the Problems

At this essay, we discuss about following problems

- find out how many charging stations would be needed and how should they be distributed between urban, suburban, and rural areas if everyone in America switched to all-electric vehicles.
- determine the optimal number, placement, and distribution of charging stations in Ireland.
- explore a proposal for evolving the charging network of Ireland.
- estimate the timeline for full evolution to electric vehicles under the growth plan.
- consider the growth plan for the building of network of chargers for different countries with different situations.
- consider how would technology affect the development of electric vehicles.

2 Our work

- First, we establish a queuing model for two charging pattern and estimate the charging stations needed in America based on the American car ownership by 2016 and some other relative data and proper assumption.
- Then, we establish a distribution model for distributing charging stations and developing the charging station net. We consider some factors including population, economy and car ownership to find out the optimal number and distribution of the stations in Ireland based on the data from *Central Statistics Office*
- Third, we try to apply the distribution model above to different countries with different situation. And find out the key factors that affect the promotion of electric vehicles.
- Fourth, we discuss how new technology will affect the promotion of electric vehicles.
- Last, we give a handout for the leaders of a wide range of countries who attending an international energy summit.

3 Queuing Model

3.1 Overview

To find out how many charging stations are needed in the U.S. if everyone switched to all-electric personal passenger vehicles, We build a queuing model. First, we make such General assumptions.

- The quantity of electric vehicles is roughly equal to the vehicles ownership.
- There are several charging points at a station.
- A charging point can only serve one electric vehicle at a time.
- The use of charging points obey the principle that firs come first served.
- Electric vehicles entering into a station will line up in the shortest line
- The number of vehicles entering a charging station obeys the Poisson distribution.

The model of queuing can be describe as following diagrams.

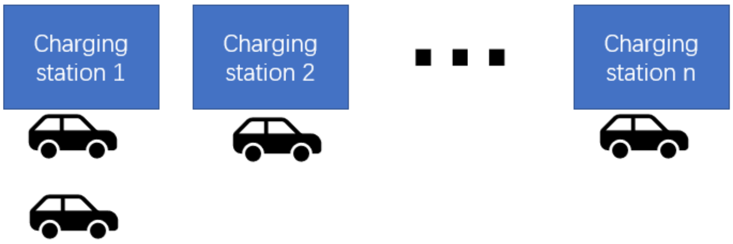


Figure 2: There are n charging points in the station

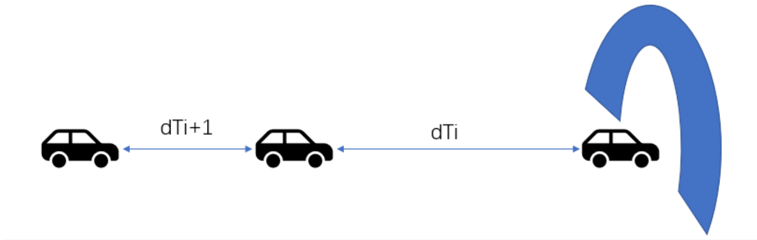


Figure 3: Several electric vehicles waiting in a line

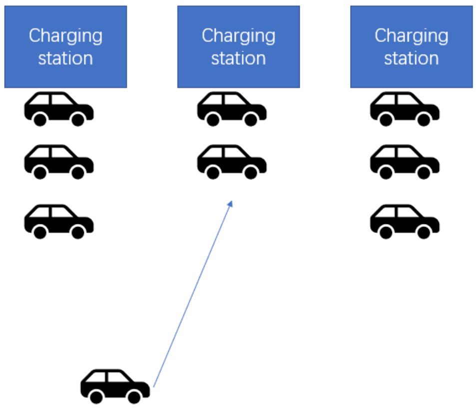


Figure 4: A coming vehicles lines up in the shortest queue

As we have assumed, the number of vehicles entering a station N obeys the Poisson distribution. That is

$$N \sim \pi(\lambda) \tag{1}$$

So the time interval between two vehicles ΔT obeys the exponential distribution. So we can get the expectation of ΔT.

$$E(\Delta T) = \lambda = \frac{T}{Qp} \tag{2}$$

- Q is the quantity of all the electric vehicles within a certain range.

- p is the probability that a vehicle enters into the station.
- T is the average time needed for charging of a electric vehicle in day.

And for the line, it is clearly that

$$T_i = T_{i0} + n_i t \tag{3}$$

- T_i is the waiting time of line i
- T_{i0} is the remaining time needed of the head vehicle of line i.
- n is the number of vehicles in the shortest line.
- t is the time needed for charging at a time.

After time ΔT, when a vehicle lines up in the currently shortest line k, we will update T_k:

$$T_k = T_k - \Delta T + t \tag{4}$$

With the queuing model, we can find out the average waiting time $\overline{T_w}$ under n charging points. Then we set the max tolerant waiting time T_{max}. Though making

$$\overline{T_w} < T_{max}$$

we can get the suitable numbers of charging station that should be built.

3.2 Destination Charging

the destination charging usually costs over 4 hours, so t = 4.5 hours. Generally speaking, destination charging is applied to the parking lot of residential area and business district. The owners will charge the cars and they them will go home to rest or go to work or shop, which we can see from the following figure.

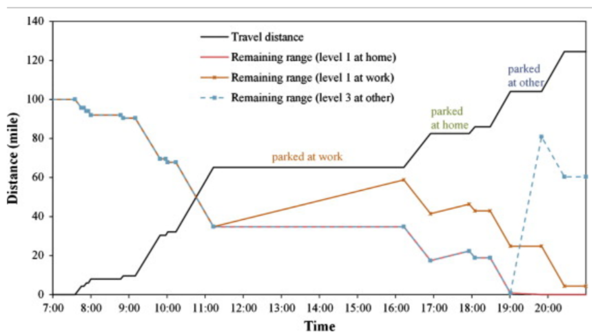
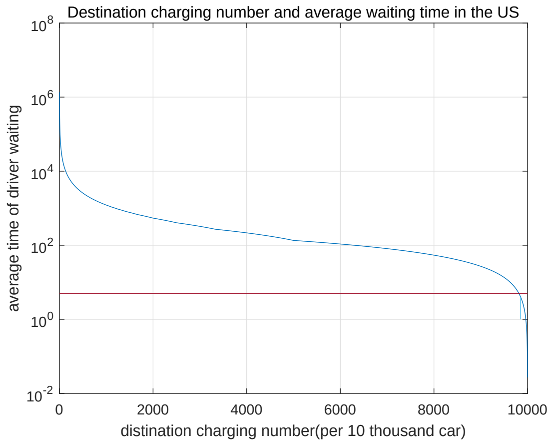


Figure 5: The pattern of behavior of driver in U.S.

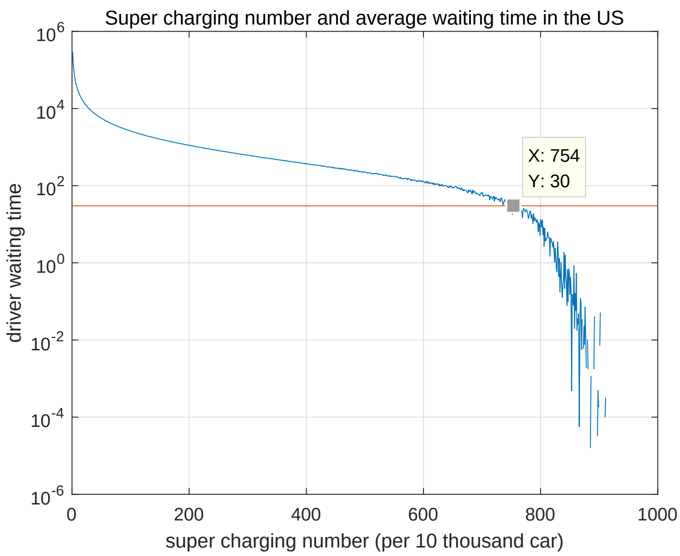
Considering that the driver's willingnesses to line up in the queue, we set T_{max} is $5min$, to simply to the model, we only consider the peak period. And from the article *Study and Recommendations of the Key Issues in Planning of Electric Vehicles Charging Facilities*, we know that. At the peak period, the probability of the need for destination charging $p = 0.6$. Through calculating by data from some area of the United States, we get following picture.



We can see that when $T_{max} < 5$, $n > 9851$. So Appropriate proportions between destination charging point and electric vehicle is $0.985 : 1$. That is, under the number of American cars in 2016, the destination charging points should be about $260M$(M means million and this usage is used in the follow text).

3.3 Supercharging

Different from the destination charging, supercharging is mostly applied in long journey. So the demand is comparably low and the tolerant time is much longer according to relative survey. Here, we set $T_{max} = 30min$ and we deal with the data all days and nights.



We can see that when $T_{maX} < 30$, $n > 754$. So Appropriate proportions between destination charging point and electric vehicle is $0.075 : 1$. That is, under the number of American cars in 2016, the destination charging points should be about $19.5M$.

3.4 Conclusion

Though the model only estimates the charging point needed instead of the station, we from out that existing charging stations are unable the meet the demand if everyone in U.S. switches to electric vehicles. According to the data from the official website of Tesla, there are only 3048 destination stations and 544 supercharging stations by 2016.
Considering the different application of two charging model, We think that every owner should have their own destination charging point for owner's satisfaction. It's also possible that some owner seldom use it, so as experience, we think that the proportion between the number of charging point and the destination stations should not be less than $1 : 1.05$. And as for supercharging station, according the existing construction of supercharging station, we suggest the proportion of $10 : 1$. That means the number of station that U.S. roughly needs is

$$19.5M/10 + 260M/1.05 = 249.56M$$

,where we regard one destination charging point as a destination charging station.

According to the classification data from *Jed Kolko*, we get the population proportion between urban, suburban and countryside is $26 : 53 : 21$. Considering there is a closed link between population and currently existed stations, we can simply distribute the number of stations between urban, suburban and countryside with the proportion of 26%, 53%, 21%.

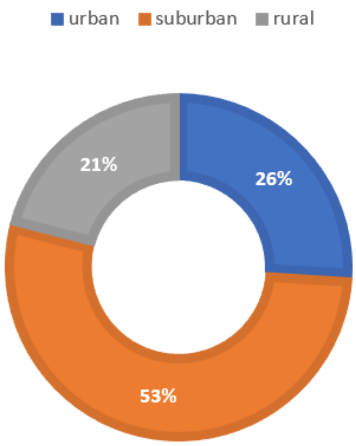
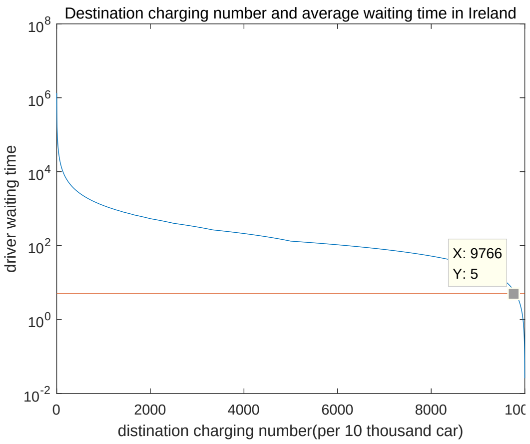


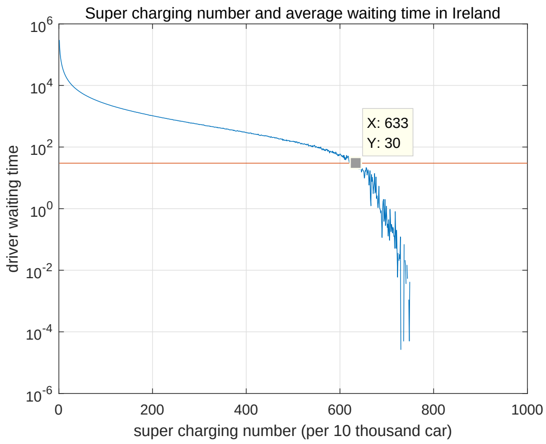
Figure 6: expected distribution between urban, suburban and countryside

4 Distribution Model

4.1 Requirement Analysis

Here, we choose Ireland to analyze. First, from data from **Central Statistics Office(CSO)** and queuing model, if Ireland migrates all their personal passenger vehicles to all-electric vehicles instantaneously, the demand for supercharging points is $0.129M$ and demand for destination points is $1.99M$. The distribution of charging station inextricably linked with the distribution of charging points. So here we can only discuss the distribution of charging points.





We set a variable Q to represent the demand for charging. The bigger Q is, the greater demand for charging is. We find out that Q is affected by population density, quantity of electric vehicles and per capita GDP with data of America by multiple linear regression. After normalized, the proportion of their weight is

$$W_p : W_n : W_{GDP} = 4.40 : 1.39 : 0.97$$

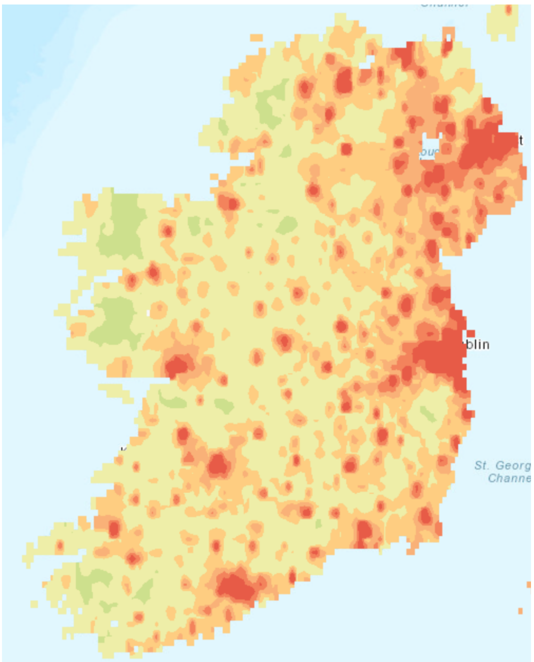
- W_p represents the weight of population density.
- W_n represents the weight of quantity of electric vehicles.
- W_{GDP} represents the wight of per capita GDP.

Here, we assume that $W_p = 65.08\%$, $W_n == 20.56\%$, $W_{GDP} = 14.36\%$. And we can easily get

$$Q_j = W_p N_j^p + W_n N_j^n + W_{GDP} N_j^{GDP} \tag{5}$$

- Q_j describes the demand for charging in unit area j.
- N_j^p represents the population density in unit area j.
- N_j^n represents the quantity of electric vehicles in unit area j.
- N_j^{GDP} represents the per capita GDP in unit area j.

Through putting data into the equation, we get the demand Q of each area. Then we use roulette algorithm to calculate the chance area j to be chosen. In this process, the bigger Q_j is , the easier to be chosen area j is. And the result is shown as the following picture. The darker the color is, the bigger the Q is, that is the greater the demand is.



4.2 Distribution Strategy

We think that the Ireland government can take this picture as an important reference to build their charging station system. For the growth plan, we suggest building charging stations based on the demand, no matter in urban or in countryside. Next, we will simulate the process to build the net from zero to a full electric vehicle net.

First we make such assumptions.

- (x_i, y_i) represents the position of the i_{th} charing point.
- d_i represents the service radium of charging station i, which we make it equal to $200km$.
- S_i represents the cover area of charging point i.
- G_i represents the benefits of charging point i, which is equal to $\sum_j^{j \subseteq S_i} Q_j$.
- once covered, Q_j decreases, $Q_j = Q_j * r$, where r represents reduction rate of demand after covered.

So the demand of each areas decreases with the construction of charging stations. Every time we build a station, we will distribute it with current circumstance. We use **particle swarm optimization(PSO)** to simulate the whole construction process. Here are the process we get.

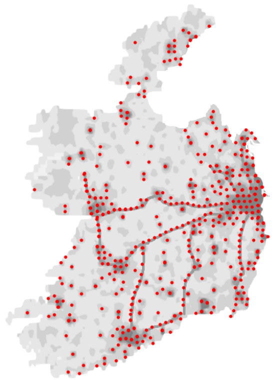


Figure 7: The first stage(10%)

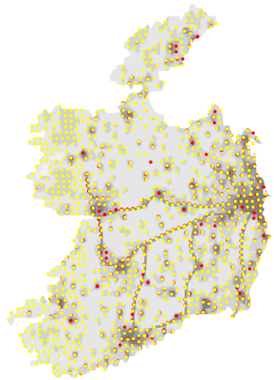


Figure 8: The second stage(30%)

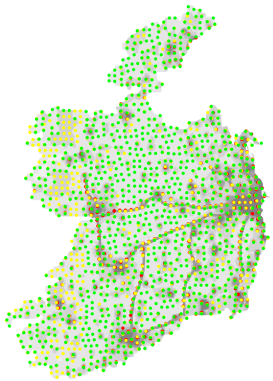


Figure 9: The third stage(50%)

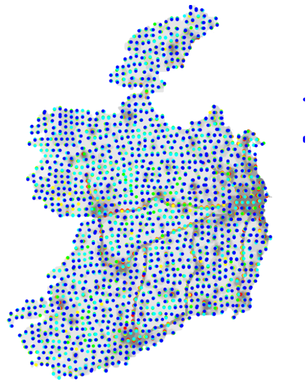


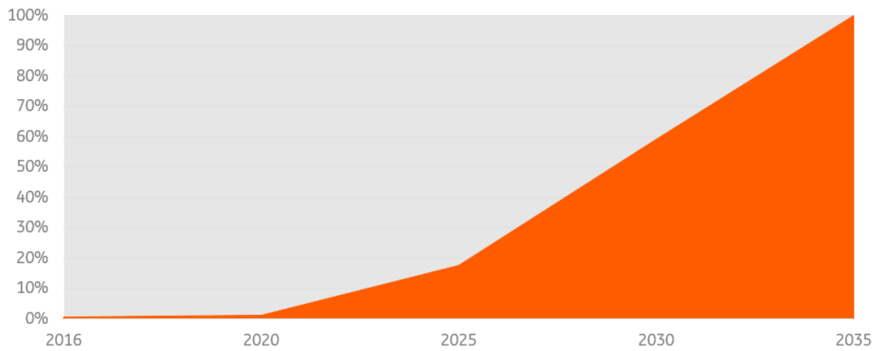
Figure 10: the fourth stage(100%)

One point represents one charging station and its service area. We can see from the 4 pictures that the stations become more and more dense.
As for detailed plan, we recommend that Ireland should focus on the area with heavy traffic such as shopping malls and office buildings. Also, they should pay attention to countryside because the people in countryside are willing to buy electric vehicle out of long distance and financial condition. At the beginning, the government should provide certain quantity of charging points at area with heavy traffic. To consummate the charging station system, the government should pay more attention to the breadth of distribution.
Here, we can also see that three key factors affect our strategy :

- Per capita GDP
- Reduction rate of demand of an area after covered, which represented by r in above assumption.
- The duration of the car's endurance. The duration determines the service radium of a station, which represented by d in above assumption.

4.3 Timeline

In order to simply our model, Our model is lack of complex cost analysis, geography analysis, policy analysis and so on. So we don't dare to estimate the timeline for the full evolution to electric vehicles in your country. But we get a reliable prediction from ING Bank.



In Ireland, referring to the data of Europe, we get the timeline as follow:

- 10%:Now to 2023. In this period, people in metropolis begin to try electric vehicle. And several charging station are built in this period.
- 20%:2023 to 2027. Electric vehicles market grows faster, the promotion process speeds up and a rough charging station system appears.
- 50%:2027 to 2030. This period is a transition period. To be well prepared for the coming revolution, Ireland government should collect and analyze the relative data about electric data.
- 100%:2030 to 2035. Electric vehicles become the mainstream choice for the whole country. This period, the government should upgrade the old charging station and establish a completed electric-traffic system.

The key factors here can be:

- per capita GDP
- the distribution of stations
- policy
- Geographical factors

5 Application in Different Country

According to data from America and model above, we find out three factors, **population density distributions**, **economic level** and **the quantity of electric vehicles in certain region** affect the demand for charging station most. We called them key factors. And we put forward two alternative plans for different circumstances.

Plan A Build charging stations in urban first, and then gradually build the charging stations in countryside.

Plan B Build charging stations based on the demand in urban, suburban or countryside.

According to the analysis and experience, for those region with high population density distributions, high economic level and certain quantity of electric cars, we advise **plan A**. Otherwise, we advise **plan B**. It can be described as following diagram.

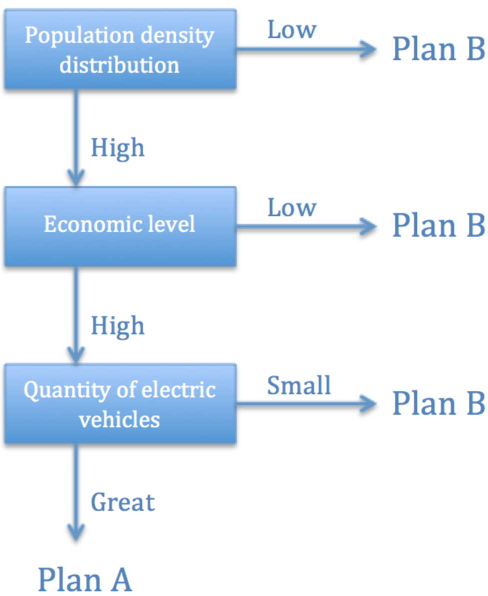


Figure 11: classification system

Countries like Singapore, we advise **plan A**. And countries like China, Saudi Arabia and so on, we advise **plan B**. They can build stations in the region that need stations most, like California in America or Beijing in China, and then complete the net based on demand.

6 Affections Brought by New Technology

- **car-share and ride-share**
  car-share and ride-share will significantly reduce consumers's willingness to buy electric cars, which indirectly decrease the charging stations. This then will also decrease the use of electric cars. So we draw a conclusion that car-share and ride-share would have a bad impact on the use of electric vehicles.

- **self-driving**
  The development of self-driving technology can increase the use of electric vehicles. Because automatic driving liberating people's hands and is likely to avoid many accidents.
  What's more, compared to traditional vehicles, electric vehicles are easily digitalized due to their design while traditional vehicles needs more processes to realize to achieve digital.

- **rapid battery-swap**
  Nowadays, charging time limits the promotion of electric vehicles. Even supercharging cannot meet the great demand for charging and the waiting time for supercharging is also intolerable when people are busy on business or way to company.
  We suggest that battery should be supplied by leasehold. And all the batteries should be charged during trough period, which can also relieve the pressure of power plants.
  There is no doubt that people are more willing to buy electric vehicles if rapid battery-swap technology and relative technology are mature enough.

- **flying car**
  flying car can also designed into electric flying car. However, limited by the development of battery, we cannot see the possibility in near future. And if flying car use fuel as its energy source, the dear expense would turn people into using electric cars.

- **Hyperloop**
  Hyperloop will be a better choice for people in long journey. However, we think that it makes no different to the use of electric vehicles. After all, trains doesn't affect the use of cars in most countries.

7 Strengths and Weaknesses

7.1 Strengths

- **Applies widely**
  In distribution model, we take many factors into consideration, which make our model can be applied to different countries with different national circumstances.

7.2 Weaknesses

- **Inaccurate data analysis**
  Take queueing model as an example, we only get the car ownership of states instead of concrete distribution, so we deal with the problem by regarding a state as a whole, which is actually different with reality.
- **Lack of cost analysis**
  Cost budgeting is an important part in deciding whether a project is feasible or not. But we only consider the demand basing on population, car ownership, economy and other factors. As a result, we have to judge if a project is feasible by some experience.

8 Handout

Both construction of charging stations and promotion of electric vehicles are complex problem. Here are some factors to be considered.

1. **the distribution of charging stations**

   Cover rate: Proper scale of construction and service radius of each station to cover the whole traffic network.

   Convenience: The distribution of the charging station should be designed based on the distribution of population and people can arrive there conveniently.

   Corresponding to city planning: Consider if the station fit with the current plan before built.

   Base on market: The distribution of station should follow the market law.

2. **Safety and quality**

   Quality: Make sure that every electric car from plant is safe.

   Periodic inspection: Periodic inspection can further reduce the safety risk.

   Battery: The batteries used in electric vehicles should be of high quality.

   Charging point: The Charging pattern should be safe enough to recharge the battery.

   Regulation: relevant regulation should be issued.

3. **Carrying capacity of power grid**

   Charging facility: The charging facilities should be coordinated with the speed of the development of the power grid in the region.

   Charging time: In order to prevent the overpressure of the power grid, the unified charging time of the battery is adjusted with the macro regulation and control of the power station.

   capacity: The power grid needs to be increased in time to meet the needs of development.

4. **Power resource**

   Green resource: Develop green new energy to support power generation gradually.

5. **Unified charge standard**

   Regulation: Unified charge standard should be issued to avoid over-high price caused by monopoly.

   Appropriate price: The price of power should based on local economic level.

Considering all factors, we suggest that gas vehicle-ban date should set from 2035 to 2045.

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