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Measuring Development of Charging Infrastructure Development in Selected Countries: Metrics and Comparison

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Summary

Charging infrastructure plays an essential role in the development of electric vehicles. In this study, we evaluate the coverage level of charging infrastructure in five countries the U.S., China, Japan, the Netherlands and Germany. Electric vehicles stock, the number of charging outlets, and road lengths are the key inputs. The results indicate that all selected countries develop electric vehicles and charging infrastructure in a positive trend. However, these countries still need to improve the coverage of charging facilities. The development levels of electric vehicles and charging infrastructure are affected by many factors, like policy, territory areas and etc.

Keywords: charging, EV, EVSE, infrastructure, policy

1 Introduction

The threat of climate change has drawn increasing attention at an international level, while the transport sector plays an essential role in carbon emission. Globally, the vehicle stock reached 1.2 billion in 2014, implying a vehicle ownership level of 180 vehicles/1,000 people [1]. In 2014, the transport sector accounted for 23% of global greenhouse gas (GHG) emissions, with around three quarters of these emissions from the road transport subsector [2].

In the U.K., the annual GHG emissions from transport increased by 17 million tons of carbon from 1970 to 2004 [3]. In China, though the official data was not published, IEA estimated that the share of CO2 emissions by the transport sector was 6% in 2000 and 8% in 2005 [4]. In the US, the transport sector is the second largest sector with 32.9% of total GHG emissions [5].

Many factors impact on the low carbon of the automotive industry, including policy, culture, product structure, energy, and infrastructure [6]. For example, countries, like China and the U.S., have taken regulations to limit the oil consumption and carbon emissions from vehicle use [7-8] and encourage citizens to use electric vehicles (EVs). Recent researchers have mainly focused on the life cycle assessment (LCA) of vehicles and fuels [9-10], considering the energy consumption and GHG emissions, to evaluate the low carbon level of road transport. Though energy saving represents the fastest way to reduce carbon emission, the lack of infrastructure partly prevents the actual decrease in fuel consumption and carbon emissions [11].

The low carbon transport infrastructure is affected by many factors. In terms of the city, factors such as the land use planning have influence on the low carbon of the transport. The urban layout directly affects the residents' travel demand, which influences the trip frequency and distance. While, preliminary researches have also been conducted to explore the relationship between the carbon emission and the development level of traditional road infrastructure, like road area per capita, density of city bus lines, etc [12-13]. The development of road construction and public transport is the main components of evaluation indexes. Finally, low carbon technology of infrastructure construction, like warm mix asphalt technique, is investigated [14]. In conclusion, different models have been set up to evaluate the low carbon level of cities and the impact of new technology on reducing GHG emissions, from the perspective of transport infrastructure.

On the other side, the promotion of electric vehicles has great influence on both conventional and charging infrastructure. For example, in many countries, the proportion of parking space with charging outlets is requested by government. Besides, the EVs usually occupy the parking space longer than conventional vehicles for long recharging time. This will influence the capacity and the mobility of parking lots and lead to more need for parking space. The optimization of charging facilities distribution and the LCA of charging facilities have been investigated by many researchers [15-16]. The number of charging station, charging efficiency and power demand have all been considered as the influence factors.

Few researchers evaluate the impact of infrastructure on the city's low carbon level, both considering the traditional infrastructure and charging infrastructure. With the aim of filling such a gap, this study compares the level of infrastructure electrification among different countries. The whole paper is organized as follows. After the introduction section, methods and data are presented. Following that, the results are discussed. The subsequent section presents the policy implications government. The final section concludes the whole study.

2 Methods and Data

2.1 Methods

Energy and environmental challenges have imposed serious restrictions to the development of internal combustion engine vehicles. EVs have advantages in energy-saving and environmental protection. During the past 5 years, both the EVs technology and market had a rapid development. Figure 1 shows the global EVs stock in recent years in major countries and the corresponding market share [17].

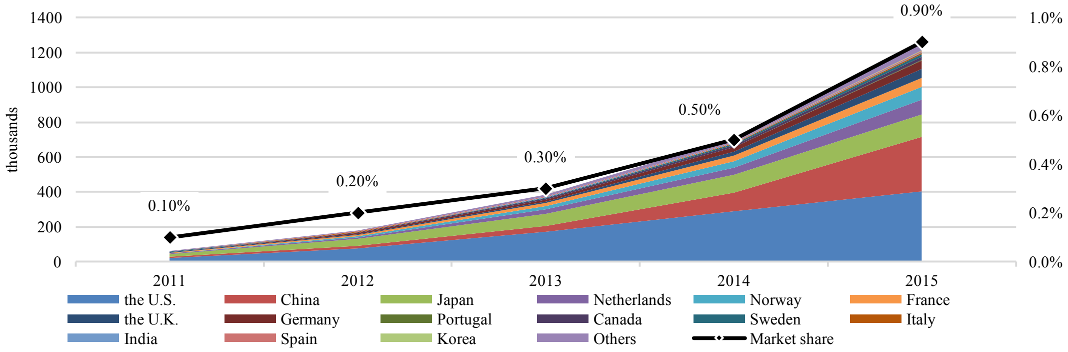

Figure 1: EVs stocks (BEV&PHEV) in 2011-2015 in the world

Figure 2 shows the publicly accessible charger outlets stock by country, from 2011 to 2015 [17-20]. The number of public charging outlets increased with the growth of the EVs stocks. Charging facilities are the energy supplement infrastructure for EVs. Establishing a service network of charging facilities is an important foundation for the development of the EVs. There exists a kind of positive interactive relation between the promotion of charging facilities and EVs markets.

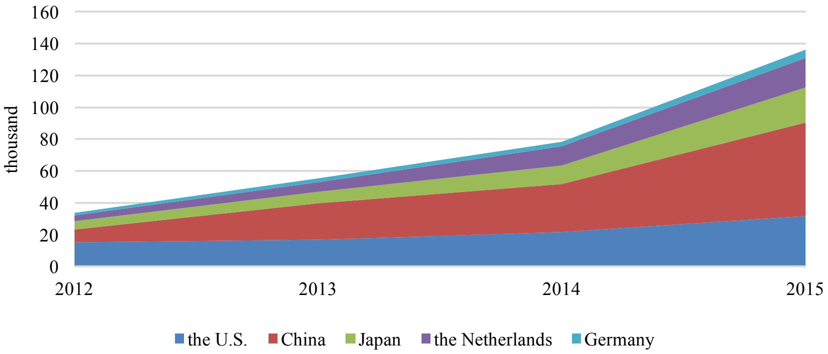

Figure 2: Public charging outlets in selected countries

In this study, a multi-indicators model is established including the factors of charging facilities, refueling stations, EVs stock, conventional vehicles stock and road length. Equation (1) calculates the density of charging outlets, as the first evaluation indicators.

$$I_1 = \frac{S_{outlets}}{(\sum l_i)} \tag{1}$$

Where,

$S_{outlets}$— the stock of charging outlets;

l_i— the road length in different road grade (km).

Equation (2) calculates the coverage of charging outlets for EVs stock.

$$I_2 = \frac{S_{outlet}}{S_{EV}} \tag{2}$$

Where,

S_{EV}— the stock of EVs.

Equation (3) compares the coverage of infrastructure between charging facilities for EVs and refueling stations for conventional vehicles.

$$I_3 = \frac{N_{EV}/S_{EV}}{N_{tradition}/S_{tradition}} \quad (3)$$

Where,

N_{EV}— the number of charging stations;

$N_{tradition}$— the number of refueling stations;

$S_{tradition}$— the stock of conventional vehicles.

2.2 Data

The U.S., China, Japan, the Netherlands, and Germany are selected for comparison in this study. The road lengths in countries was maintained at relatively stable levels in recent years, so only the latest data of the road lengths are considered, as shown in Table 1 [21-23]. For different road grades, the demands for charging facilities are different. For instance, in China, charging facilities only prevail in urban areas, and few are constructed on highways and in rural areas. The difference in the density of charging facilities between urban roads and highways are not considered.

Table 1: The road length and the number of refueling stations in selected countries

Country	Road length (km)	The number of refueling stations
The U.S.	6,683,300	114,474
China	4,577,000	96,800
Japan	1,218,772	35,000
The Netherlands	139,295	4,163
Germany	645,000	14,209

The conventional vehicle stocks, from 2012 to 2015, in these countries are shown in Figure 3 [24-27].

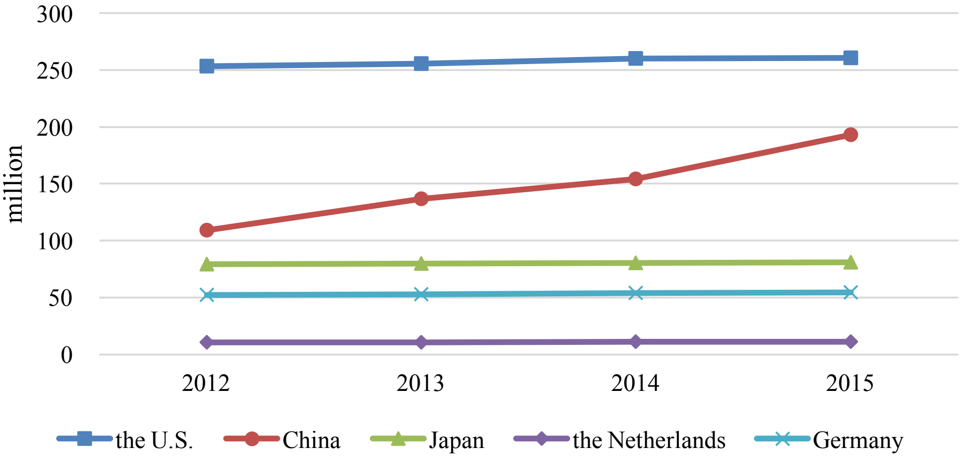

Figure 3: The conventional vehicle stock in different countries

The numbers of charging outlets are shown in Figure 2. We assume that each charging station consists of four charging outlets, so the number of charging stations is a quarter of the charging outlets. The number of conventional refueling stations in each country are shown in Table 1 [28-30]. In some developed countries, the number of refueling stations is decreasing, due to the development of EVs. For instance, in Japan, the number of refueling stations has already been overtaken by the total number of charging outlets, though many outlets belong to private owners.

3 Results and Discussion

The U.S. had a larger number of charging outlets in the earlier years than did other countries, due to the earlier development of the EVs market. Besides, the U.S. maintained a rapid growth rate of the charging outlets in 2014 and 2015. The growth rate of charging outlets number in China was the highest. In 2012, the number in China was around half of that in the U.S. However, China had almost twice the number of the U.S. in 2015. Japan was also in a rapid development period of charging infrastructure in 2014 and 2015. The incremental quantity of Japan was basically the same as that of the U.S. The Netherlands and Germany are both European countries. In comparison, the charging outlets in the Netherlands developed faster than that in Germany.

The density of charging outlets, in unit per kilometre, is calculated by Equation (1). Figure 4 illustrates the results. The Netherlands had a much higher density than the others, followed by Japan, Germany, the U.S. and China. In 2015, the order changed into the Netherlands, Japan, China, Germany and the U.S. It can be found that China keeps rapid development in charging infrastructure and keeps improving the coverage. The result of the U.S. is not as good as that of compared with other countries.

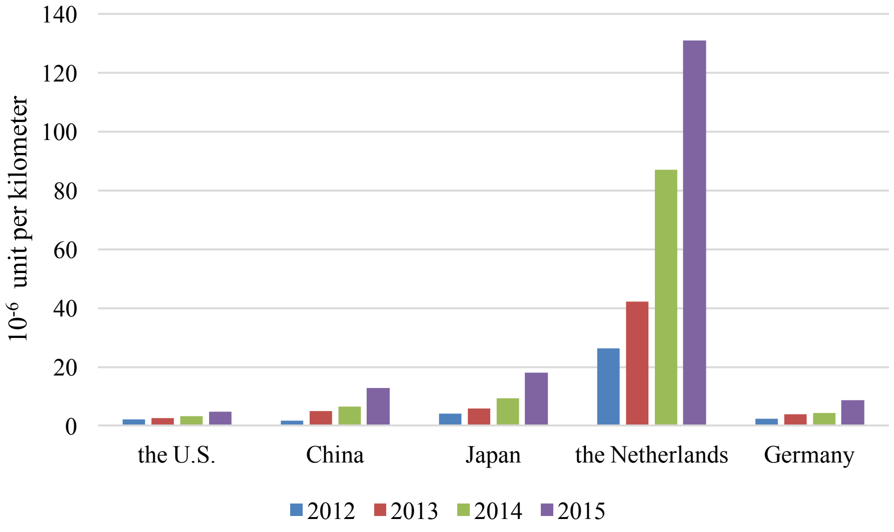

Figure 4: The comparison of charging outlets distribution density

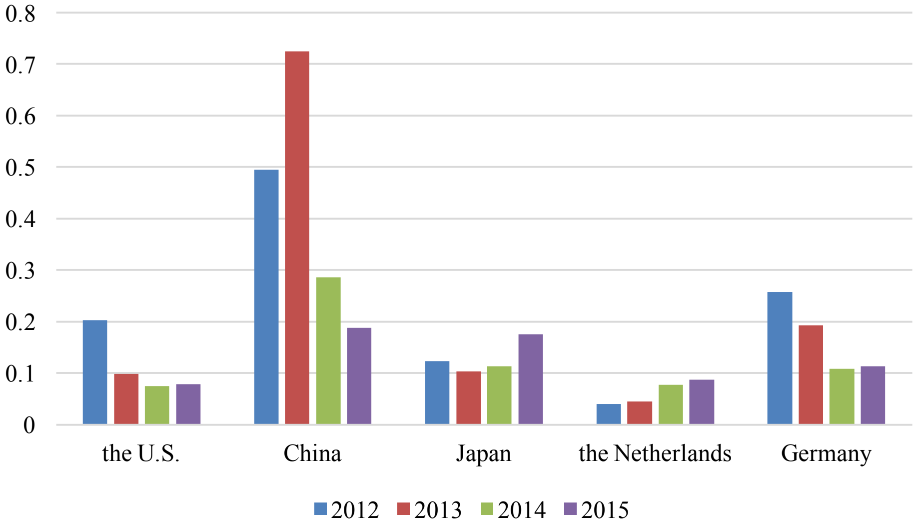

Figure 5: The comparison of charging outlets per EVs own

Figure 5 indicates the ratio of charging outlets to EVs stock, the results of Equation (2). China has the highest result, but is in a decreasing trend. In 2014, the number of EVs in China is around three times of that in 2013. However, the charging outlets only 1.3 times that in 2013. The more rapid growth of EVs than that of charging outlets leads to the indicator decline. The results of the U.S. and Germany also declined, but in 2015, they both had a small increase. The results of Japan and the Netherlands are in uptrend. Japan has a higher ratio than the Netherlands.

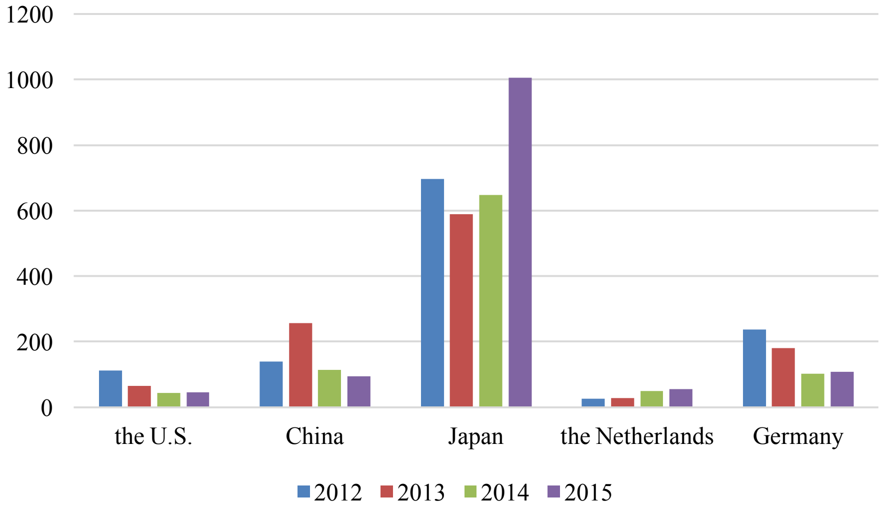

Figure 6: The comparison between charging facilities for EVs and refueling station for conventional vehicle

As for the third indicator, Japan has the highest level, as Figure 6 shows. After a short decline, the result in Japan had a sustained increase in 2014 and 2015. That means a positive development of charging infrastructure in Japan. Germany and China show similar results. Both of them are on a declining trend. The results indicate that the development of charging infrastructure in these two countries is not compatible with the development of EVs, when compared to conventional vehicles. However, the reasons may be different for China and Germany. In China, under the promotion policies, there is a rapid growth in the number of EVs as mentioned before. It is hard to ask corresponding facilities to develop so fast. In Germany, conventional vehicles have advantages in long historical time. It will take a long period for EVs and corresponding infrastructure to entrant in the market. The result of the U.S. is low and downwards. The number of charging outlets does not conform to the number of EVs. The country layout in the U.S may lead to this results. Private charging outlets are popular for EVs in the U.S, which is not considered in this study. The result of the Netherlands is the lowest. Though the value of the Netherlands is lower than other countries, the Netherlands is in a stable and increasing developing trend.

When all the indicators are considered, the Netherlands shows a good result among these five countries, with a high EVs stock and coverage of charging outlets. Though the number of EVs in China increases quickly, the corresponding infrastructure does not develop in accordance with the EVs. The situation in the U.S. is almost the same. The U.S. promotes EVs earlier than other countries, and its charging infrastructure has a stable increasing rate. However, when considering the EVs stock, the charging infrastructure still need to be promoted. The result of Japan also illustrates a good EVs infrastructure development. Though the lack of refueling station, to some extent, leads to the high value of the third indicator, the increasing trend means a good develop tendency. Germany is a European country with a long history of conventional vehicles. It may take a long period for Germany to adapt to the development of EVs. However, the emission policy in the EU may promote this trend.

4 Policy Implications

Under the government promotion, the sales and stock of EVs in China really increase rapidly, but the infrastructure will be the limitation of EVs in the future for usage. Besides, compared with the Netherlands, China has huge land area and unbalanced economic development. EVs and charging outlets are only popular in urban area in recent period. It will take a long time for China to promote EVs into mid-western regions. The construction of charging infrastructure in remote area will promote the development of EVs, and will expand the travel range of EVs. When compared with the U.S., private charging outlets may be not suitable for most Chinese users, so public charging infrastructure will be more important for China EVs development. Not only the number is essential, but also the distribution.

Japan and Germany are both automotive power countries, and master the advanced technology in automotive industry. From the result perspective, they are also in a good developing trend of charging infrastructure. A long history of conventional vehicle development has both advantages and disadvantages. The technical reserves will help the new type vehicle research and development, but they may also hold back the promotion of EVs. Compared with these two countries, the automotive industry in China began relatively late, and the technology is relatively weak. However, China automotive companies, like BYD, continues to achieve breakthrough in the field of EVs. China should take advantages of this trend, and promote charging facilities and EVs.

The Netherlands is a good sample of promoting EVs and developing charging facilities. Due to the small territory area, it is easier for the Netherlands to develop EVs. As for the U.S., though it began to develop EVs earlier than other countries, it still will take a long period to promote EVs nationally.

5 Conclusion

To meet with the restriction of carbon emission and energy problem, the development of EVs market is the general trend. Affected by many factors, like the territory area, technology and policy, the development levels of charging infrastructure in different countries are also different. In this study, we evaluate the development of charging facilities in the U.S., China, Japan, the Netherlands and Germany. Though all of these countries have a positive trend in the development of EVs and charging infrastructure, they still need to improve the density of charging outlets to meet with the increasing EVs number. The evaluation did not consider the unbalanced distribution of charging outlets in countries. In the future study, the distribution can be analysed.

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