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Marginal Analysis of the HFCVs Industrialization: Commercialization Scale and the CO_2 Emission Reduction

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Abstract. Focus on the hydrogen fuel cell vehicle industrialization barriers, the paper applies the marginal analysis into the CO_2 emission reduction of the HFCV. Based on the outputs of the GREET model, the CO_2 emission reduction amount of the HFCVs, the CO_2 emissions amount of HFCVs and the scale of the HFCV are calculated separately. Then we build the formulas of the above variables so that the marginal curve of the CO_2 emission reduction and the commercialization scale of HFCVs are mapped. The conclusion shows the marginal analyze could play a useful role in the CO_2 emission reduction estimation of the HFCV industrialization.

Introduction

Unlike the petroleum economy system, the hydrogen economy pertains to a world fundamentally different. Hydrogen as a fuel, and a source of electricity, could be produced in sufficient amounts domestically, cleanly, and cost-effectively from a variety of resources, including such renewable as sunlight, biomass and water [1]. Hydrogen-powered fuel cells and engines would be as common as the gasoline and diesel engines of the late 20th century—they would power cars, trucks, buses, and other vehicles, as well as homes, offices and factories.

The United Nations estimated that over 600 million people in urban area worldwide were exposed to traffic-generated air pollution [2]. Therefore, traffic related air pollution is drawing increasing concerns worldwide. Hybrid electric vehicles hold the potential to considerably reduce greenhouse gas (GHG) emission and other gas pollution. A significant increase of electric vehicles will be seen in the near future, to limit the increase in fuel consumption and exhaust emissions. How to estimate Hydrogen Fuel Cell Vehicles (HFCV) reduce the CO_2 emission? It is still the barriers of its industrialization and commercialization [3, 4]. This paper tries to map the marginal curve of the scale and the CO_2 emission reduction of the HFCVs industry.

Methodology and Framework

Firstly, we estimate the CO_2 emission reduction data of the HFCVs through the GREET model developed by Argonne National Laboratory [5]. Then with the marginal analysis method, a typical economic application method, the marginal effect curve of the CO_2 emission reduction amount and the emission reduction costs of the HFCVs are drawn and the economic contribution of the hydrogen fuel cell vehicles in CO_2 emission reduction also becomes obvious. The industrialization of the HFCVs is on the infant stage in the world. U.S. had gotten great progress in its commercialization so the experiment data comes from DOE reports.

Marginal analysis is compared to the additional expenditure and additional income; they are equal to the critical point. It is the point in which the benefit received from the investment is equal to the output loss. Additional expenditures are independent variables, and additional income is the dependent variable. The dependent variable changes with the changes of independent variables. In our marginal analyze of the CO_2 emission reduction map of the HFCVs, the independent variable is the number of HFCVs and the dependent variable is the total CO_2 emission reductions amount of the HFCVs. All the data of the CO_2 emission reduction of HFCVs come from four kinds of hydrogen sources [6].

It could be divided into three stages to analyze the entire energy cycle system of HFCV [7]. The first is the vehicle operating stage. There are no CO_2 emissions during this sub-cycle, and the other two loops will produce CO_2 emissions. The second is the vehicle circulation stage, and the CO_2 is occurred in four main stages, namely: liquid, batteries, ADR and materials. The third is the energy cycle stage [8]. The reference frame is ordinary fuel vehicles in GREET model to estimate the CO_2 emissions of HFCVs.

The Estimation of the CO_2 Emission and the Scale of the HFCVs

With the development of science and technology, the number of HFCVs has a corresponding growth which could be found from several U.S. institute studies. In these studies, the U.S. Department of Energy [9] developed a scenario calculation method which has relatively large influence. The data obtained by this method are consistent with the recent international study model results. Taken together, these findings show that with the development and application of hydrogen technology, the number of HFCVs has a rapid increase and with the technology advancing, the rate of growth will gradually increase, from thousands of vehicles in the first, to about 200 million, and then to 60 million, and to the remote 220 million as the scenario model estimated. Table 1 shows the number of HFCVs with the stage of hydrogen technology development.

Table 1 The number of HFCVs with the tage of hydrogen technology development

Stage	1	2	3	4	5	6	7	8
Number(unit)	$3*10^3$	$2*10^6$	$1.15*10^7$	$3*10^7$	$6*10^7$	$1.05*10^8$	$1.6*10^8$	$2.2*10^8$

The CO_2 emission reduction amount of the HFCVs could be concluded as the equation (1).

$$R_s = R_r - R_{hf} \quad (1)$$

R_s is the CO_2 emission reduction amount of the HFCVs; R_r is the CO_2 emissions amount of reference frame; R_{hf} is the CO_2 emissions amount of HFCVs.

The CO_2 emission reduction amount of the HFCV per year per unit could be concluded as the equation (2).

$$R_y = R_a / S \quad (2)$$

R_y is the CO_2 emission reduction amount of the HFCV per unit; R_a is the CO_2 emission reduction amount of the HFCV; S is the scale of the HFCV.

The CO_2 emission reduction ratio of the HFCV could be concluded as the equation (3).

$$A = R_s / R_r \quad (3)$$

A is the CO_2 emission reduction ratio of the HFCV.

According to the GREET model and the data in Table 1, combined with existing data and formulas (1), (2) and (3), we can get the data in Table 2. The data shows the amount of the HFCVs' CO_2 emission, the amount and rate of the HFCVs' CO_2 emission reductions compared with the fuel cell vehicle with the growth of the number of HFCVs.

Table 2 Hydrogen fuel cell vehicle CO_2 emissions statistics

HFCVs' number [unit]	HFCVs' CO_2 emission [million tons]	Reference Frame's CO_2 emission [million tons]	CO_2 emission reduction [million tons]	Units of HFCVs' CO_2 emission reduction [tons]	CO_2 emission reduction rate [%]
3000	1500	1500	0	0	0.00%
2000000	1390.2	1400	9.8	4.9	0.70%
11500000	1350	1400	50	4.347826087	4.00%
30000000	1300	1450	150	5	10.34%
60000000	1255.5	1550	294.5	4.908333333	19.00%
105000000	1100	1600	500	4.761904762	31.25%
160000000	900	1650	750	4.6875	45.00%
220000000	680	1700	1020	4.636363636	60.00%

Figure 1 can be drawn based on the data in Table 2, that is, the CO_2 emissions of HFCVs and frame of reference which changes with the scale, as well as HFCVs' CO_2 emission reduction. The horizontal axis is the size of the HFCVs; the longitudinal axis is the amount of the CO_2 emissions. The horizontal axis of reference frame is its scale which has not been reflected in the figure. The horizontal axis is set to coincide with the horizontal axis of the HFCVs, so that the chart has comparability.

The first curve shows how the amount of the HFCVs' CO_2 emissions changes with the development of hydrogen technology. The second curve represents the amount of CO_2 emissions of the reference frame. It can be seen from the figure that with the growth of the size of HFCVs, the amount of the HFCVs' CO_2 emission gradually decreases.

The third curve describes that how the scale of HFCVs' CO_2 emission reduction trends with the development of hydrogen technology. It can be seen from the figure, with the growth of the HFCVs, HFCVs' CO_2 emission reductions gradually increased, and the rate of growth gradually increases.

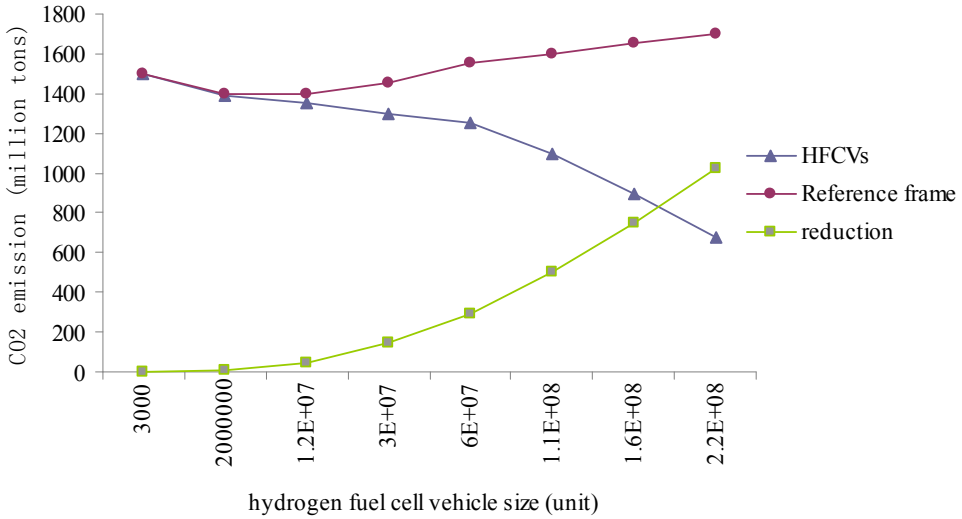

Fig.1 HFCVs and frame of reference changes with the scale of CO_2 emissions and the CO_2 emission reduction of HFCVs (unit: million tons)

CO_2 Marginal Emission Reduction Curve of the HFCV

Taking Column 1 and 4 of table 1 to the equation (2) results into the amount of the HFCVs' CO_2 emissions (column 5 of table 1). According to equation (3), the HFCVs' CO_2 emission rate can be derived (Column 6 of Table 1). Figure 2 can be drawn from the Column 1, 5 and 6 of Table 1 (per unit of the amount and rate of the HFCVs' CO_2 emission reduction with the growth of the size of HFCVs). From the first curve can be seen that when the scale of HFCV grows from 3000 to 2 million, the HFCVs' CO_2 emission reductions increase from 0 to 4.9 tons per unit. When scale continues to grow, the unit emission reductions declines, but then rises to 5 tons. After that, the unit emission reductions will remain basically at this level.

The second curve is the marginal abatement curve for HFCVs replacement. With the development and utilization of hydrogen technologies, more and more HFCVs are sold. HFCVs' CO_2 emission reduction rate continuously increases. In 2020, the HFCVs' CO_2 emissions rate is only 0.7% comparing with the frame of reference automotive group. In 2035, the rate rises to 19%, and in 2050, the rate jumps to 60%.

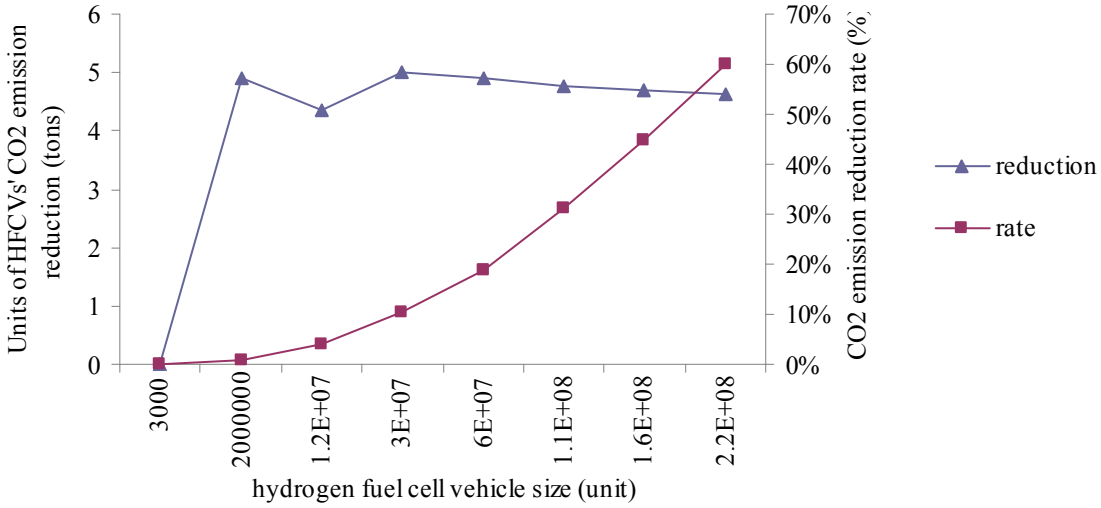

Fig.2 Per unit of the amount and rate of the HFCVs' CO_2 emission reduction with the growth of the size of HFCVs

Conclusion

By means of the GREET model, it is impossible to estimate the environmental contribution of the hydrogen energy transportation. This is precisely one of the constraints of the HFCV industrialization. The marginal analyze of the related variables shows the HFCVs' CO_2 emission reduction rate continuously increases. In 2020, the HFCVs' CO_2 emissions rate is only 0.7% comparing with the frame of reference automotive group. In 2035, the rate rises to 19%, and in 2050, the rate jumps to 60%. According to the curve, Hydrogen Fuel Cell Vehicle will greatly improve the traditional fuel transportation emissions along with its industrialization and commercialization.

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