Comparison between Subsidy and Cap-and-Trade Policy on Electric Logistics Vehicles Leasing System

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Abstract. Electric logistics vehicles (ELVs) can reduce carbon emissions of logistics industry. However, the logistics company is reluctant to adopt ELVs due to the shortages of high purchasing cost, short driving range, and long charging time. This research studies ELVs leasing system which consists of an ELVs manufacturer, an ELVs rental company, and a logistics company. The influence of purchasing subsidies and Cap-and-Trade policy(C&T) on the ELVs leasing system is analyzed and compared. It is found that the logistics company prefers the subsidy policy when the driving range of ELVs is within a certain range. Otherwise, the logistics company prefers C&T policy. For the rental company and the manufacturer, when the subsidy is within a certain range, C&T policy is more profitable. Otherwise, the rental company and the manufacturer prefer the subsidy policy. If the emission reduction benefit is high enough, the C&T policy can lead to more emission reduction. Otherwise, the subsidy policy is better for the environment.

Keywords: electric logistics vehicles; leasing system; subsidy policy; cap-and-trade policy.

1. Introduction

Industry and transportation are significant contributors to climate change [1], where transportation accounting for 25% of global carbon emissions. Electric logistics vehicles (ELVs) are one of the best alternatives to conventional fuel logistics vehicles (CFLVs) interims of emissions reduction and economy [2]. However, ELVs have a higher purchase cost [3], especially due to the significant proportion of battery degradation cost, which decreases operational efficiency.

The governmental subsidy is a direct and convenient way to promote the adoption of ELVs. Wang et al. [4] explored the effect of government subsidies on innovation in Chinese firms producing ELVs. Wang et al. [5] used empirical data from listed EVs companies to assess the impact of subsidies on corporate financial performance. Yang and Tang [6] discussed and analyzed the effectiveness and welfare consequences of various subsidy programs. However, long-term subsidy will cause fiscal pressure to the government. Cap-and-trade (C&T) has been widely applied in other industries as an effective tool to reduce carbon emissions. Therefore, it is necessary to explore the introduction of C&T in the logistics industry to encourage the adoption of ELVs to substitute CFLVs.

On the other hand, some studies explored issues related to EVs leasing. Miao et al. [7] studied the profitability model of electric vehicle rental services based on time-based subscription pricing. Tang et al. [8] established an online optimal leasing strategy and a multi-vehicle online leasing strategy to promote the sustainable development of EV. Zefeng et al. [9] proposed the customer requirements and technical elements of EV leasing and sales. For logistics companies, the way of leasing ELVs can also encourage them to adopt ELVs and reduce the operating costs of them [10].

However, rare research studies ELVs leasing system. Considering the shortcoming of ELVs, such as the short driving range and inefficient use due to long recharging time, this study compares the effects of subsidies and C&T policy in promoting the adoption of ELVs. It helps supply chain members to make optimal decisions to achieve maximum profits, and also provides policy suggestions for the government to promote ELVs and reduce carbon emissions.

2. The Models

2.1 Problem Description

This research considers an ELVs leasing system which is composed of the manufacturer, the rental company and the logistics company.

The manufacturer who produces the ELVs decides the wholesale price (w) of each ELV. The manufacturing cost for each vehicle is c_m, and the effective driving range is d kilometers.

The rental company decides the rental price (p) and the number of ELVs purchased from the manufacturer (k). k is determined by the rental distance of the logistics company (L_e), which is expressed as $k = \frac{L_e}{d}$. The rental company receives a purchasing subsidy (s_e) from the government for each ELV. Each vehicle incurs depreciation costs (c_d).

The logistics company needs a total driving distance of L with unit profit (r) which can be achieved by CFLVs and renting ELVs. The unit fuel cost of a CFLV is c_f per kilometer, and the unit electricity cost of an ELV is c_e per kilometer. With the driving distance (L_e) increases, the battery degrades gradually which leads to an increase in the number of recharges for the same driving distance. Suppose the lost profit during each charge is m. Then the total lost cost for driving distance (L_e) because of recharging for the logistics company is simplified as $\frac{mL_e{}^2}{2}$. The logistics company determines the driving distance with ELVs (L_e).

2.2 Model-S: Subsidy Policy

The government, e.g. in Shenzhen City provides subsidies in accordance with the battery capacity of ELVs. The revenue of the manufacturer (π_S^M), the rental company (π_S^R), and the logistics company (π_S^L) are shown in equation (1)-(3), respectively.

$$\pi_S^M(w) = k(w - c_m) \tag{1}$$

$$\pi_S^R(p) = \frac{L_e}{d}(p + s_e) - k(w + c_d) \tag{2}$$

$$\pi_S^L(L_e) = rL - \frac{L_e}{d}p - (L - L_e)c_f - L_e c_e - \frac{m}{2}L_e{}^2 \tag{3}$$

Proposition 1. By using Stackelberg game theory to solve the above model, it is obtained the optimal wholesale price (w_S^*), rental price (p_S^*), the purchase quantity of ELVs (k_S^*) of the rental company, as well as the logistics company's driving distance with ELVs (L_{eS}^*).

$$w_S^* = \frac{c_m - c_d + s_e - c_e d + c_f d}{2} \qquad p_S^* = \frac{c_d + c_m - s_e - 3c_e d + 3c_f d}{4}$$

$$k_S^* = \frac{Le_S^*}{d} = \frac{s_e - c_m - c_d - c_e d + c_f d}{4d^2 m} \qquad L_{eS}^* = \frac{s_e - c_m - c_d - c_e d + c_f d}{4dm}$$

The associated optimal profits of the manufacturer (π_S^{M*}), the rental company (π_S^{R*}), and the logistics company(π_S^{L*}) are following:

$$\pi_S^{M*} = \frac{(c_d + c_m - s_e + c_e d - c_f d)^2}{8d^2 m} \qquad \pi_S^{R*} = \frac{(c_d + c_m - s_e + c_e d - c_f d)^2}{16d^2 m}$$

π_S^{L*}

$$= \frac{\begin{array}{c} c_d{}^2 + 2c_d c_e d - 2c_d c_f d + 2c_d c_m - 2c_d s_e + c_e{}^2 d^2 - 2c_e c_f d^2 + \\ 2c_e c_m d - 2c_e d s_e + c_f{}^2 d^2 - 2c_f c_m d - 32 Lmc_f d^2 + 2c_f d s_e + c_m{}^2 - 2c_m s_e + 32 Lmd^2 r + s_e{}^2 \end{array}}{32d^2 m}$$

The proof of proposition 1：Take the inverse solution method, according to (3) formula, make $\frac{\partial \pi_S^L}{\partial L_{eS}} = 0$ can get $L_{eS} = \frac{c_f - c_e + \frac{p}{d}}{m}$, and then find $\frac{\partial^2 \pi_S^L}{\partial L_{eS}{}^2} = -m < 0$. It is proved that the profit function of the logistics company (π_S^L) is a concave function about the L_e. Therefore, there exists an optimal

solution of L_{eS}^*. Similarly, other optimal solutions are found and then the revenue as well. The proof of Proposition 1 is completed, and the rest of Proposition 1 can be proved similarly.

2.3 Model-P: C&T

Under the C&T policy, the government issues a fixed carbon emission allowance (Q) to the logistics company. The carbon price is p_e. The carbon emissions per kilometer for CELV is denoted as e. Therefore, the trading amount of allowance in the carbon market is $(L - L_e)e - Q$. The revenue of the manufacturer (π_P^M), the rental company (π_P^R), and logistics company (π_P^L) are separately shown in equation (4)-(6).

$$\pi_P^M(w) = k(w - c_m) \tag{4}$$

$$\pi_P^R(p) = p\frac{L_e}{d} - k(w + c_d) \tag{5}$$

$$\pi_P^L(L_e) = rL - \frac{L_e}{d}p - (L - L_e)c_f - L_e c_e - [(L - L_e)e - Q]p_e - \frac{m}{2}L_e^2 \tag{6}$$

Proposition 2. By using Stackelberg game theory to solve Model-P, we can obtain the optimal wholesale price (w_P^*), rental price (p_P^*), number of ELVs ordered by the rental company (k_P^*) and the logistics company's required driving range of ELVs(L_{eP}^*).

$$w_P^* = \frac{c_m - c_d - c_e d + c_f d + dep_e}{2} \qquad p_P^* = \frac{c_d + c_m - 3c_e d + 3c_f d + 3dep_e}{4}$$

$$k_P^* = \frac{Le_P^*}{d} = \frac{dep_e - c_m - c_d - c_e d + c_f d}{4d^2 m} \qquad L_{eP}^* = \frac{dep_e - c_m - c_d - c_e d + c_f d}{4dm}$$

And the corresponding optimal profits of the manufacturer (π_P^{M*}), the rental company (π_P^{R*}) and the logistics company(π_P^{L*}) are following:

$$\pi_P^{M*} = \frac{(c_d + c_m + c_e d - c_f d - dep_e)^2}{8d^2 m} \qquad \pi_P^{R*} = \frac{(c_d + c_m + c_e d - c_f d - dep_e)^2}{16d^2 m}$$

$$\pi_P^{L*} = \frac{\begin{aligned}&c_d{}^2 + 2c_d c_e d - 2c_d c_f d + 2c_d c_m - 2c_d dep_e - 2c_d dhr - 2c_d s_e + c_e{}^2 d^2 - 2c_e c_f d^2 \\ &+2c_e c_m d - 2c_e d^2 ep_e - 2c_e d^2 hr - 2c_e ds_e + c_f{}^2 d^2 - 2c_f c_m d + 2c_f d^2 ep_e \\ &+2c_f d^2 hr - 64Lac_f d^2 r - 32Lmc_f d^2 + 2c_f ds_e + c_m{}^2 - 2c_m dep_e - 2c_m dhr \\ &-2c_m s_e + d^2 e^2 p_e{}^2 + 2d^2 ehp_e r - 64Lad^2 ep_e r - 32Lmd^2 ep_e + d^2 h^2 r^2 \\ &+64Qad^2 p_e r + 32Qmd^2 p_e + 64Lad^2 r^2 + 32Lmd^2 r + 2dep_e s_e + 2dhrs_e\end{aligned}}{32d^2(m + 2ar)}$$

3. Comparative Analysis

In this section, it is conducted comparisons of the optimal decisions, the profits of each member in the system, and the total carbon emissions under the subsidy and C&T policies.

3.1 Analysis of Optimal Decisions

The impact of parameters (s_e and p_e) on optimal decisions under two policies are analyzed and compared which is shown in Proposition 3 and 4.

Proposition 3. The influences of parameters on the optimal decisions are:

(a)$\frac{\partial L_{eS}^*}{\partial s_e} > 0$, $\frac{\partial k_S^*}{\partial s_e} > 0$, $\frac{\partial p_S^*}{\partial s_e} < 0$, $\frac{\partial w_S^*}{\partial s_e} > 0$

(b)$\frac{\partial L_{eP}^*}{\partial p_e} > 0$, $\frac{\partial k_P^*}{\partial p_e} > 0$, $\frac{\partial p_P^*}{\partial p_e} > 0$, $\frac{\partial w_P^*}{\partial p_e} > 0$

These results show that subsidy can help reduce the cost for the rental company, which leads to lower the rental prices and higher demand for ELVs. Therefore, the manufacturer raises its sales prices and production quantity, and thus gains more profits. Under the C&T policy, a rise in carbon price can encourage the logistics company to use more ELVs to avoid carbon emission cost. In this situation, the rental company and the manufacturer will increase their prices and quantities of ELVs.

Proposition 4. Comparison of optimal decisions between subsidy and C&T policies is as follows:

(a) $p_P^* > p_S^*$

(b) $\begin{cases} s_e = dep_e, \ w_P^* = w_S^*, \ L_{eP}^* = L_{eS}^* \\ s_e < dep_e, \ w_P^* > w_S^*, \ L_{eP}^* > L_{eS}^* \\ s_e > dep_e, \ w_P^* < w_S^*, \ L_{eP}^* < L_{eS}^* \end{cases}$

Here, dep_e is defined as emission reduction benefit within effective distance d. The rental price under subsidy policy is always lower than that under the C&T policy. When the subsidy amount (s_e) equals dep_e, the optimal wholesale price and demand of ELVs are the same under both policies. When the subsidy amount is larger than dep_e, the subsidy policy can encourage more demand on ELVs, which resulting in higher wholesale price. When the subsidy amount is below dep_e, C&T policy can stimulate demand and increases wholesale prices.

3.2 Profits Comparison of Different Policies

By analyzing the profits of the logistics company, the manufacturer, the rental company and the overall supply chain under two policies, the following propositions are obtained.

Proposition 5. The impact of subsidies, carbon price, electricity price, and fuel price on profits.

(a) $\frac{\partial \pi_S^M}{\partial s_e} > 0, \ \frac{\partial \pi_S^R}{\partial s_e} > 0, \ \frac{\partial \pi_S^L}{\partial s_e} > 0, \ \frac{\partial \pi_S^M}{\partial c_e} < 0, \ \frac{\partial \pi_S^R}{\partial c_e} < 0, \ \frac{\partial \pi_S^L}{\partial c_e} > 0, \ \frac{\partial \pi_S^M}{\partial c_f} > 0, \ \frac{\partial \pi_S^R}{\partial c_f} > 0.$

(b) $\frac{\partial \pi_P^M}{\partial p_e} > 0, \ \frac{\partial \pi_P^R}{\partial p_e} > 0, \ \frac{\partial \pi_P^M}{\partial c_e} < 0, \ \frac{\partial \pi_P^R}{\partial c_e} < 0, \ \frac{\partial \pi_P^L}{\partial c_e} > 0, \ \frac{\partial \pi_P^M}{\partial c_f} > 0, \ \frac{\partial \pi_P^R}{\partial c_f} > 0.$

This proposition indicates that under both policies, an increase in electricity price leads to decreasing profits for all members. On the other hand, an increase in fuel prices causes an increase in demand for ELVs, resulting in increased profits for both the manufacturer and rental company. Under subsidy policy, subsidy can increase profits for all members. Under the C&T policy, an increase in carbon price will lead to an increase in demand and a rise in profits for both the rental company and the manufacturer.

Proposition 6. The comparison of the logistics company's profits under two policies is shown in Table 1.

Table 1. Profit Comparison of the Logistics Company

s_e	d	π_S^{L*} vs π_P^{L*}
$s_e \geq 2(c_d + c_m)$	$d_1 \leq d < d_2$	$\pi_S^{L*} \geq \pi_P^{L*}$
	$d \geq d_2 \ d < d1$	$\pi_S^{L*} \leq \pi_P^{L*}$
$s_{e1} \leq s_e < 2(c_d + c_m)$	$d_1 < d \leq d_2$	$\pi_S^{L*} \geq \pi_P^{L*}$
	$0 < d \leq d_1$ $d > d_2$	$\pi_S^{L*} \leq \pi_P^{L*}$
$0 \leq s_e \leq s_{e1}$	$d_2 \leq d \leq d_1$	$\pi_S^{L*} \geq \pi_P^{L*}$
	$0 < d \leq d_2$ $d \geq d_1$	$\pi_S^{L*} \leq \pi_P^{L*}$

where $s_{e1} < 2(c_d + c_m)$, $s_{e1} = \frac{2c_d ep_e + 2c_m ep_e}{2c_f - 2c_e + 2ep_e}$, $d_1 = \frac{2c_d + 2c_m - s_e}{2c_f - 2c_e + ep_e}$, $d_2 = \frac{s_e}{ep_e}$

For the logistics company, when subsidies are high($s_e \geq 2(c_d + c_m)$), ELVs with driving range within a certain range($d_1 < d < d_2$) will generate higher profits under the subsidy policy. If the driving range of ELVs is long, the C&T policy is more beneficial to the logistics company. With medium subsidies($s_{e1} \leq s_e < 2(c_d + c_m)$), if the driving range is in mid-level, i.e. $d_1 < d < d_2$, the logistics company prefer subsidy policy. Otherwise, C&T policy can provide greater benefits. When the subsidies are small($s_e \leq s_{e1}$), the results are similar except for different boundary. If the driving range is in a certain rang($d_2 \leq d \leq d_1$), subsidy policy is more profitable for the logistics company. Otherwise, C&T policy is better.

Proposition 7. The comparison of the rental company and the manufacturer's profits in different policies is shown in Table 2.

Table 2. Profit comparison of the rental company and the manufacturer

s_e	$\pi_S^{M\&R*}$ vs $\pi_P^{M\&R*}$
$s_e \geq dep_e$	$\pi_S^{M\&R*} \geq \pi_P^{M\&R*}$
$s_e \leq dep_e - 2(-c_d - c_m + c_f d - c_e d)$	$\pi_S^{M\&R*} \geq \pi_P^{M\&R*}$
$dep_e - 2(-c_d - c_m + c_f d - c_e d) < s_e \leq dep_e$	$\pi_S^{M\&R*} \leq \pi_P^{M\&R*}$

When the subsidy is relatively large ($s_e \geq dep_e$) or small ($s_e \leq dep_e - 2(-c_d - c_m + c_f d - c_e d)$), subsidy policy is beneficial to both the rental company and the manufacturer. When the subsidy is within a range ($dep_e - 2(-c_d - c_m + c_f d - c_e d)) < s_e \leq dep_e$), C&T policy is more profitable for them. According to Proposition 4, in this scenario, the demand, wholesale price and rental price are higher under C&T policy. Therefore, their profits are also higher.

Proposition 8. The comparison of supply chain's profits in different policies is shown in Table 3.

Table 3. Profit comparison of supply chain

e	s_e	m	π_S^{T*} vs π_P^{T*}
$e > Q$ $L \cdot e \geq Q$	$0 \leq s_e < dep_e$	$0 \leq m < m_1$	$\pi_S^{T*} \leq \pi_P^{T*}$
		$m \geq m_1$	$\pi_S^{T*} \geq \pi_P^{T*}$
$e \geq Q$	$s_e \geq dep_e$	$m \geq 0$	$\pi_S^{T*} \geq \pi_P^{T*}$
$e \leq Q$	$0 \leq s_e < dep_e$	$m \geq 0$	$\pi_S^{T*} \leq \pi_P^{T*}$
$e < Q$ $L \cdot e < Q$	$s_e \geq dep_e$	$0 \leq m < m_1$	$\pi_S^{T*} \geq \pi_P^{T*}$
		$m \geq m_1$	$\pi_S^{T*} \leq \pi_P^{T*}$

where $m_1 = \dfrac{-7(s_e - dep_e)(2c_d + 2c_m - s_e + 2c_e d - 2c_f d - dep_e)}{32d^2 p_e (Q - L \cdot e)}$

In the situation of the total emissions exceed the allowance ($L \cdot e \geq Q$), when the subsidy is less than the emission reduction benefit ($s_e < dep_e$), the C&T policy is more beneficial than the subsidy policy for increasing the system profit only if the lost profit caused by recharging is small ($m < m_1$). When subsidies are larger than the emission reduction benefit ($s_e \geq dep_e$), the subsidy policy is always more beneficial.

The other situation is that the carbon allowance is small and cannot cover the total emission. The results are opposite. The subsidy policy is better than the C&T policy for the system only when the subsidy is greater than the emission reduction benefit ($s_e \geq dep_e$) and the lost profit caused by recharging is small. In other scenarios, the C&T policy is more beneficial.

3.3 Total Carbon Emissions Comparison of Different Policies

By analyzing and comparing the magnitude of the optimal total carbon emissions of the supply chain between different policies, Proposition 9 can be obtained.

Proposition 9. The comparison of total carbon emission under different policies.

$$\begin{cases} s_e = dep_e, & E_S^* = E_P^* \\ s_e > dep_e, & E_S^* < E_P^* \\ s_e < dep_e, & E_S^* > E_P^* \end{cases}$$

Total carbon emissions decrease as subsidies increase. When subsidy equals to the emission reduction benefit dep_e, the total carbon emissions under two policies are the same. If subsidy is more than dep_e, the subsidy policy can encourage the rental of ELVs, and thereby reduce the use of

CFLVs and total carbon emissions. When subsidy is less than dep_e, the C&T policy can incentive the logistics company to use ELVs, thereby reducing total carbon emissions.

4. Conclusions

This study researches on an electric logistics vehicle leasing system including an ELVs manufacturer, an ELVs rental company and a logistics company. The optimal operational decisions of all members are obtained. In addition, the impact of the subsidy policy and the C&T policy on their profits and total carbon emissions are compared. Based on the analysis, several managerial insights for the supply chain members and government are provided as follows:

ELVs with driving range within a certain range, the subsidy policy can promote the demand of ELVs. However, when the subsidy is small, the ELVs with smaller or larger driving range is not adopted. In this scenario, the C&T policy can increase the use of ELVs and is more favored by the logistics company and can be applied in the logistics industry.

In terms of the environment, if the emission reduction profit is high enough, the C&T policy can lead to more emission reduction. Otherwise, the subsidy policy is better. In other words, the subsidy policy is suitable for the initial development stage when the driving range of ELVs is short or the carbon price is low. With increasing driving range or when the carbon market is mature, it is the better choice to include the logistics industry in the C&T system.

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