Research on the Income Distribution Mechanism of the New Energy Charging Network Alliance

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Abstract. The alliance of the new energy charging network is a cooperative organization consisting of car manufacturers, charging facility manufacturers, and operators. Reasonable income distribution is the key to forming and sustaining the alliance. According to the cooperation period, this article divides the alliance types into short-term and long-term cooperation. In the context of short-term cooperation, this article employs the Nash negotiation model to establish a fixed-ratio distribution mechanism. For long-term alliances, this article innovatively proposes a dynamic adjustment mechanism, introduces investment, risk sharing, and cooperative contribution to modify the Shapley value for preliminary income distribution, and then conducts Nash negotiation adjustment based on the satisfaction levels of all members in the alliance. The data results show that the fixed ratio model increases the short-term cooperation benefits by 19-24%, while the dynamic adjustment mechanism increases the benefits of long-term alliance members by 21-22%. By contrast, the dynamic adjustment mechanism narrows the gap in the income distribution ratio and effectively balances the pattern of benefit distribution.

Keywords: Game theory, charging network, income distribution.

1. Introduction

As an important transportation energy infrastructure, the charging network service plays a significant role in supporting the convenient charging of electric vehicles [1]. In 2024, China's new energy vehicle production will exceed 10 million. With the development of charging infrastructure, charging alliances come into being, greatly improving the convenience of charging networks [2]. In the process of continuous expansion of the charging alliance scale, the conflict of interest among members continues to escalate due to the unfairness of income distribution, ultimately leading to the breakdown of the alliance.

Therefore, coordinating the income distribution ratio is the key to ensuring the stable development of the alliance. Existing studies have shown that the Shapley value and the kernel method, as traditional distribution methods, only focus on the differences in economic contributions of alliance members while ignoring the differences between members within the alliance [3, 4]. With the development of research methods, experts have proposed an improved Shapley value model based on correction factors. Haiping et al. introduce risk factors to modify the Shapley value [5]. Hu et al. advocate determining the income distribution ratio based on contribution [6]. Song Jianmin believes that in addition to contribution and risk factors, investment ratio and participation enthusiasm should also be considered [7]. Li Jinchao et al. further introduce factors such as investment proportion, risk size, social responsibility, and management investment, and establish an improved Shapely value income distribution model [8]. In addition, there are also many studies on adjusting the income distribution ratio based on satisfaction levels. Zheng Shaoyu et al. combine the income distribution mechanism with the Nash negotiation model by introducing the satisfaction, thus forming an optimized plan for the profit distribution of public rental housing projects [9]. Ge Qiuping et al. comprehensively consider the four main factors affecting the benefit distribution of the industry-university-research cooperation and constructs an asymmetric Nash negotiation model based on satisfaction level [10]. These studies show that the Nash negotiation model based on satisfaction levels can effectively adjust the preliminary income distribution results to achieve a more fair and satisfactory distribution plan.

There are two main limitations of income distribution plans in existing research. firstly, the influence of the time dimension is not fully considered, and secondly, there is a lack of optimized research on specific distribution subjects. To solve these issues, this article takes the new energy charging network alliance as the research object and innovatively proposes a two-stage distribution mechanism based on the time dimension. In the short term, this article adopts the Nash negotiation model to determine the optimal distribution ratio. In the long term, this article constructs a modified Shapley value model and adjusts the distribution plan dynamically by introducing satisfaction. Empirical analysis shows that the distribution mechanism is not only theoretically reasonable but also shows significant effectiveness in practical applications, providing a scientific basis for the operational decision of the new energy charging network alliance.

2. Model Building

2.1. Problem Description

Consider charging network alliance consisting of car manufacturers, charging facility manufacturers, and operators. Automobile manufacturers provide customers. Charging facility manufacturers focus on research, production and sales of charging equipment's. Charging facility operators are responsible for the layout, construction, and operation management of charging facilities. This article focuses on the issue of income distribution and attempts to find a distribution mechanism that can reflect both fairness and efficiency in order to encourage stable cooperation among all participants in the alliance.

2.2. Basic Assumption

This article constructs a cooperative game model for the new energy charging network alliance, which satisfies the following assumptions:

(1) Rational person assumption. Each participant ensures that the distributed benefits after cooperation are not lower than the benefits of their independent operation.

(2) The overall benefits are distributed to each participant completely without residual benefits.

(3) The cost of each negotiation is fixed.

(4) The status of each participant in the new energy charging network alliance is asymmetric.

2.3. Symbol Definition

Table 1 shows the definition of symbol.

Table 1. Symbol definition

symbol	The Meaning of symbol
C_i	The cost invested by the i-th participant. $i = 1,2,3$
V_m	The overall benefits after forming cooperation
G_i	The profits of the i-th participant when operating independently. $i = 1,2,3$
U_i	The profits of the i-th participant after forming cooperation. $i = 1,2,3$
k	All negotiation costs
γ_i	The negotiation ability of the i-th participant. $i = 1,2,3$

2.4. Model Solution

2.4.1A fixed ratio distribution plan

Assume that after forming the charging network alliance, each participant can obtain the proportion of cooperative distribution $a_i, i = 1,2,3$. The income respectively is:

$$U_i = a_i(V_m - k) - C_i \tag{1}$$

The conditions for cooperation must meet:

$$U_i \geq G_i \tag{2}$$

According to the Nash negotiation model, participants need to negotiate to maximize the following equation [11]:

$$NP(a_i) = \prod_{i=1}^{3}[U_i - G_i]^{\gamma_i} \tag{3}$$

By introducig U_i into the above formula:

$$NP(a_i) = \prod_{i=1}^{3}[a_i(V_m - k) - C_i - G_i]^{\gamma_i} \tag{4}$$

Take the logarithm of the above formula, introduce the Lagrange multiplier, and construct the Lagrange multiplier:

$$L(a_i) = \sum_{i=1}^{3} \gamma_i \ln(a_i(V_m - k) - C_i - G_i) + \lambda(1 - a_1 - a_2 - a_3) \tag{5}$$

Find the first derivative:

$$L^{'}(a_i) = \gamma_i \frac{V_m - k}{a_i(V_m - k) - C_i - G_i} - \lambda \tag{6}$$

Let $L^{'}(a_i) = 0$:

$$a_i = \frac{\gamma_i}{\lambda} + \frac{C_i + G_i}{V_m - k} \tag{7}$$

According to $\sum_{i=1}^{3} a_i = 1, \sum_{i=1}^{3} \gamma_i = 1$:

$$\lambda = \frac{1}{1 - \sum_{i=1}^{3} \frac{C_i + G_i}{V_m - k}} \tag{8}$$

By arranging, the final result is:

$$a_i^{*} = \gamma_i \left(1 - \sum_{i=1}^{3} \frac{C_i + G_i}{V_m - k}\right) + \frac{C_i + G_i}{V_m - k} \tag{9}$$

The results show that:

(1) When $\gamma_i \sum_{i=1}^{3} \frac{C_i + G_i}{V_m - k} = \frac{C_i + G_i}{V_m - k}, a_i^{*} = \gamma_i$, the proportion of cooperative distribution is exactly equal to the negotiation ability.

(2) If $C_i + G_i$ increases, this means that the company has higher profits while operating independently or needs to pay more costs to join the cooperation, so it requires more compensation for benefits.

(3) When γ_i increases, it means when the negotiation ability of the i-th company develops, it can obtain a larger distribution ratio.

(4) Fixed costs k are introduced in the form of net benefits $V_m - k$, indicating that the higher the negotiation costs, the less total benefits, thus affecting the distribution ratio.

(5) Since V_m is the expected benefits, it does not change over time. The long-term use of fixed ratio distribution may lead to the breakdown of the alliance. Therefore, fixed ratio distribution is more suitable for short-term cooperation.

2.4.2A dynamically adjusted distribution plan

If the alliance is a long-term cooperation, considering the dynamics and complexity of the charging network income distribution, the distribution process can be divided into the following two stages.

Stage1: Preliminary income distribution based on modified Shapley value

According to the Shapley value, the benefits of each participant are [12]:

$$\varphi_i = \sum_{s \in S_i} \omega(|s|) \left[u(s) - u\left(\frac{s}{\{i\}}\right)\right], i = 1,2,3 \tag{10}$$

In the formula, φ_i represents the income distribution value obtained by each participant. S_i is all subsets of the set that contain member i, and $|s|$ is the number of elements in the subset.

$$\omega(|s|) = \frac{(|s|-1)!(n-|s|)!}{n!}, n = 3 \tag{11}$$

By introducing investment, risk sharing, and cooperative contribution to modify the Shapley value, construct a normalized matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \tag{12}$$

a_{ij} represents the proportion of the i-th participant in the j-th correction factor. Through the AHP method to obtain the influence coefficient $\lambda = [\lambda_1\ \lambda_2\ \lambda_3]^T$. Then $\beta = A \times \lambda = [\beta_1\ \beta_2\ \beta_3]^T$, the adjusted income of the alliance participants according to the above formula is:

$$U_i{}' = U_i + \left(\beta_i - \frac{1}{3}\right) \times V_m, i = 1,2,3 \tag{13}$$

The income distribution coefficient r_i is:

$$r_i = \frac{U_i{}'}{\sum_{i=1}^{3} U_i{}'}, i = 1,2,3 \tag{14}$$

Stage2: Nash negotiation adjustment based on the satisfaction levels

If the participants are not satisfied with the Preliminary income, they propose a new benefit distribution plan $Q_i = (q_{i1}, q_{i2}, q_{i3})$, q_{ij} represents the benefit distribution coefficient of the j-th participant in the benefit distribution plan that the i-th subject considers, where $\sum_{j=1}^{3} q_{ij} = 1, 0 < q_{i1}, q_{i2}, q_{i3} < 1$. Let the ideal distribution coefficient of the i-th participant be $q_i^+ = \max(q_{1i}, q_{2i}, q_{3i})$, and the non-ideal distribution coefficient be $q_i^- = \min(q_{1i}, q_{2i}, q_{3i})$, then the ideal distribution plan and the unsatisfactory distribution plan are respectively $Q^+ = (q_1^+, q_2^+, q_3^+), Q^- = (q_1^-, q_2^-, q_3^-)$. According to the asymmetric Nash negotiation model [13]:

$$maxZ = \prod_{i=1}^{3} \left[\frac{r_i}{q_i^+} - \frac{q_i^-}{q_i^+}\right]^{\gamma_i} \tag{15}$$

$$s.t. \begin{cases} q_i^- \le r_i \le q_i^+ \\ \sum_{i=1}^{3} r_i = 1 \end{cases} \tag{16}$$

Through the Kuhn-Tucker, the optimal solution of the profit distribution coefficient is:

$$r_i^* = q_i^- + \left(1 - \sum_{i=1}^{3} q_i^-\right) \frac{\gamma_i q_i^+}{\sum_{i=1}^{3} \gamma_i q_i^+} \tag{17}$$

If the influential degree of the satisfaction is $\phi \in [0,1]$, the value is given by the expert. Thus, the adjusted profit distribution coefficient is:

$$r_i' = r_i + \phi(r_i^* - r_i) \tag{18}$$

If any alliance participant is not satisfied with the distribution plan, the above process can be repeated until a result is satisfactory to everyone. At the end of each stage, the distribution plan should be re-evaluated and the weight should be adjusted according to the progress of the project.

3. Case Analysis

Now, there is a charging network alliance consisting of car manufacturers, charging facility manufacturers, and operators. After evaluation, the cooperative alliance can obtain a total income of 10 million yuan, and the negotiation cost is estimated to be 1 million yuan. The investment costs of each participant are 1 million yuan, 800,000 yuan, and 1.2 million yuan, respectively. If they choose not to cooperate, the independent operation income of each alliance participant is 1.8 million yuan, 1.3 million yuan, and 2 million yuan. The income of the alliance between car manufacturers and charging facility manufacturers, car manufacturers and operators, and charging facility manufacturers and operators is 3.55 million yuan, 4.2 million yuan, and 3.8 million yuan, respectively. Suppose that the negotiation ability of the alliance participants accounts for 32%, 25%, and 43%, respectively.

3.1. Scenario 1: Short-term Cooperation

Table 2 shows the business operation strategies in the short-term cooperation. On the whole, the overall benefits of the alliance participants have increased to different degrees after the cooperation. The data shows that in the alliance income distribution mechanism, there is a significant correlation between the independent operation profits and the member distribution coefficient. Specifically, charging facility operators benefit from higher independent operation profits, equipped with negotiation ability, thus ensuring a higher share in the alliance in the distribution system. In contrast, charging facility manufacturers are in a weak position due to their relatively limited independent operation profits, and the final profit distribution ratio is reduced accordingly.

According to the fixed ratio distribution formula (unit: 10,000 yuan).

Table 2. Income distribution plan in short-term cooperation

company	independent operation income	Cooperative coefficient	distribution coefficient	Revenue improvement rate
car manufacturer	180	215.2	0.3426	19.56%
Facility manufacturer	130	157.5	0.2582	21.15%
Facility operator	200	247.3	0.3992	23.65%

3.2. Scenario 2: Long-term Cooperation

Stage1: Preliminary income distribution based on modified Shapley value

According to the Shapley value, the preliminary income distribution for car manufacturers, charging facility manufacturers, and operators is respectively 3.408 million yuan, 2.958 million yuan, and 3.633 million yuan.

Suppose that experts score car manufacturers, charging facility manufacturers and operators on the investment, risk sharing and cooperative contribution, and construct a normalized matrix A:

$$A = \begin{bmatrix} 0.3463 & 0.2917 & 0.3750 \\ 0.2727 & 0.2500 & 0.2917 \\ 0.3810 & 0.4583 & 0.3333 \end{bmatrix}$$

According to AHP method, the influence intensity of the three correction factors is:

$$\lambda = [0.4\ 0.3\ 0.3]^{\mathrm{T}}$$

According to the above formula, the comprehensive correction weight can be calculated:

$$\beta = A \times \lambda = [0.34\ 0.27\ 0.39]^{T}$$

The adjusted incomes are as follows:

$$U_1{}' = 340.8 + (0.34 - \frac{1}{3}) \times 1000 = 346$$

$$U_2{}' = 234.06, U_3{}' = 419.85$$

The corresponding income distribution coefficient is:

$$r_1 = \frac{346}{1000} = 34.60\%$$

$$r_2 = 23.41\%, r_3 = 41.99\%$$

Stage2: Nash negotiation adjustment based on the satisfaction levels

If during the project, any participant is dissatisfied with the income distribution coefficient. Suppose that the income distribution plans proposed by all participants are as follows:

$$\mathrm{Q}_1 = (0.37,0.24,0.39), \mathrm{Q}_2 = (0.31,0.36,0.0.33), \mathrm{Q}_3 = (0.32,0.26,0.42)$$

The ideal and the unsatisfactory benefit distribution plans are:

$$\mathrm{Q}^{+} = (0.37,0.36,0.42), \mathrm{Q}^{-} = (0.31,0.24,0.33)$$

According to the formula, the optimal solution of the profit distribution coefficient is

$$r_1^* = 0.3465, r_2^* = 0.2678, r_3^* = 0.3857$$

According to experts, the adjustment coefficient $\phi = 0.7$:

$$r_1' = 0.3464, r_2' = 0.2593, r_3' = 0.3943$$

Table 3 shows the business operation strategies in the long-term cooperation. The data shows that, whether in the short-term or long-term cooperation, all participants can obtain higher income than independent operation. It is worth noting that different distribution mechanisms will significantly affect the income ratio of each participant: in short-term cooperation, the income distribution coefficients of each participant are (0.3426, 0.2582, 0.3992). In long-term cooperation, by comprehensively considering investment, risk sharing, and cooperative contribution and adjusting based on the satisfaction level, the optimized distribution coefficients are finally determined to be (0.3464, 0.2593, 0.3943).

Table 3. Income distribution plan in long-term cooperation

company	independent operation income	Cooperative coefficient	distribution coefficient	Revenue improvement rate
car manufacturer	180	218.688	0.3464	21.49%
Facility manufacturer	130	158.556	0.2593	21.97%
Facility operator	200	242.756	0.3943	21.38%

By comparing short-term and long-term data, it shows that in the long-term cooperation, although charging facility manufacturers are still in a relatively weak position compared to the dominant members, their income distribution ratio increases compared with short-term cooperation. This result reflects that to maintain the stability and sustainability of the cooperative relationship, the dominant members of the alliance actively cede part of their interests to support the development needs of the disadvantaged members, embodying the dynamic balance and the win-win concept under the long-term cooperation.

4. Conclusion

This article introduces the time dimension, comprehensively considers factors such as investment, risk sharing, and cooperative contribution, establishes a modified Shapley value benefit distribution model, and then adjusts the distribution plan according to the satisfaction level. The effectiveness and rationality of the model are verified through numerical simulations. The research results indicate that alliance cooperation significantly improves the level of benefits for all participants involved. As time goes by, the increase in profits of each member tends to be consistent. In this mechanism, the advantaged participant transfers some benefits to the disadvantaged participant, thereby ensuring the long-term stability and reliability of the alliance.

Based on the research results, the following two suggestions are given to the New Energy Charging Network Alliance:

Firstly, select a model according to the cooperation time. For newly established or short-term partners with clear goals, it is recommended to adopt a fixed ratio distribution mechanism based on the Nash negotiation model to quickly reach a preliminary consensus and reduce negotiation costs and uncertainties. While in long-term cooperation, a dynamic adjustment plan should be selected to make the distribution more reflective of the investment, risk-taking, and cooperation contributions, ensuring that the allocation plan is both fair and incentive. Secondly, it is recommended that charging facility manufacturers in a disadvantaged position can increase investment in technology, change the weight of technology contribution in the correction factor and develop negotiation ability, so that it can obtain a larger proportion of the profit distribution coefficient. At the same time, the government is called on to provide more policy support and subsidies for technology to enhance the overall industry competitiveness and innovation capabilities.

This study still has some limitations, mainly reflected in the method of determining weights. AHP method requires researchers to compare and subjectively score each influencing factor, which is inevitably affected by personal judgment bias. To enhance the scientificity of the research, subsequent studies can consider introducing more objective weight determination methods, such as the entropy weight method and principal component analysis, to build a more accurate and reliable evaluation system. This direction will help to further improve the accuracy and application value of research results.

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