A coupling coordination development model of new energy electric vehicles and ecological environment

Jiaqi Shi[#*], Xinman Li[#], Zhimu Hu

School of Economics, Northeastern University at Qinhuangdao, Qinhuangdao 066004, China

Abstract. Analysing the degree of coupling and coordination between new energy electric vehicles and ecological environment in China is of great significance to optimize and enhance the development of new energy vehicles in China. This paper constructs the evaluation index system of China's new energy development and ecological environment level respectively, and analyses the coupling and coordination level of the two based on the game theory combination empowerment method, the simulated annealing optimization projection tracing evaluation model and the coupling coordination degree model. The results show that the coupling degree of coordination gradually increases from 0.292 in 2010 to 0.828 in 2021, and the impact of the development of new energy electric vehicles on the ecological environment in China presents a positive and positive development year by year.

1 Introduction

With global climate change and environmental pollution becoming increasingly prominent, the Chinese government is actively promoting the development of new energy vehicles to reduce dependence on traditional fuel vehicles, lower carbon emissions and improve air quality [1]. At the same time, protecting and improving the ecological environment has become one of the important goals of China's development. Therefore, it is of urgent practical significance to study the degree of coupling and coordination between new energy electric vehicles and ecological environment in China.

Analysing the degree of coupling and coordination between China's new energy electric vehicles and the ecological environment is of great significance for optimizing and enhancing the development of new energy vehicles in China [2]. By analysing the degree of coupling and coordination between new energy electric vehicles and the ecological environment, we can firstly rationally allocate resources, promote the development of new energy vehicles in harmony with ecological environmental protection, and avoid resource waste and environmental damage. Secondly, it can help decision makers formulate more effective policies and measures to promote the sustainable development of new energy vehicles while protecting the health of the ecological environment. Third, it can assess the impact of new energy electric vehicles on the environment, including the benefits of reducing carbon emissions, improving air quality and reducing noise pollution, and provide a scientific basis for environmental protection and sustainable development [3]. Finally, it can guide the development direction and strategy of the new energy vehicle industry, promote the innovation and upgrading of the industry, and promote the development of clean energy and sustainable transportation.

This study aims to deepen our understanding of the development of the Chinese market for new energy electric vehicles by constructing an evaluation index system for the development of new energy vehicles and the ecological environment. Based on a series of mathematical models, the study analyses the coupling relationship and coordination degree between China's new energy electric vehicles and the ecological environment. The findings of this research will contribute to providing scientific foundations for policy-making and industrial development in the field of new energy electric vehicles. Additionally, it will offer theoretical support and policy recommendations for the sustainable development of China's new energy electric vehicle industry.

2 Methodology

2.1 Model analysis

To measure the coordinated development of China's new energy vehicles and the ecological environment, we first construct an index system for the development of new energy vehicles and the ecological environment. Then, based on game theory, combined weighting, and particle swarm optimization projection tracking evaluation models, we assess the levels of energy vehicle development and the ecological environment separately. Finally, we introduce a model for coordinated development to analyse the coupling relationship and degree of coordination between China's new energy

# These authors contributed equally to this work as co-first authors.
* Corresponding author's email: 202110044@stu.neuq.edu.cn

electric vehicles and the ecosystem, in order to measure the impact of new energy electric vehicles on the ecosystem.

2.2 Index system construction

2.2.1 New energy electric vehicle development index system

Based on extensive literature research [4-5], this study follows principles such as systematicity, hierarchy, scientific, measurability, and operability. From the perspectives of economic development, technological progress, market demand, infrastructure, and policy support, we have selected 15 indicators to characterize the evaluation index system for the development level of China's new energy. These indicators are shown in Table 1.

Table 1. New energy electric vehicle development index system.

Primary indicator	Secondary indicator
Economic development	Gross domestic product (GDP) Population Secondary industry output Consumption expenditure per capita
Technological progress	Power battery installed capacity Patent publication New energy vehicle invention patent authorization Maximum range of pure electric vehicles
Market demand	Sales volume Relative market share Average annual price of gasoline Registration of new energy vehicle-related enterprises
Infrastructure	Public charging pile capacity Installed power generation capacity
Policy support	Number of positive government policies

2.2.2 Ecological environment index system

Similarly, through extensive literature research [6-7], this study follows principles such as systematicity, hierarchy, scientific, measurability, and operability. From the perspectives of energy, water, land, ecology, air, and environment, we have selected 20 indicators to characterize the evaluation index system for China's ecological environment level. These indicators are shown in Table 2.

Table 2. Ecological environment index system.

Primary indicator	Secondary indicator
Energy	Energy consumption per unit of GDP Clean energy utilization rate
Water	Water consumption per unit of GDP Harmonization of soil and water Urban sewage treatment rate
Land	Cultivated land area ratio Per capita food possession
	Proportion of counties with excellent and good ecological quality in the national territory Forest coverage rate
Biological	Proportion of local species categorized as being in danger of extinction Number of invasive alien species Ocean health index Biological carrying capacity
Air	Pollution index CO_2 emissions per capita SO_2 emissions
Environment	Climate index Environmental performance index Environmental protection investment index Non-hazardous treatment rate of domestic garbage

2.3 Game theory combination weighting model

2.3.1 Analytic hierarchy process

The Analytic Hierarchy Process (AHP) belongs to the subjective weighting method and is a qualitative and quantitative, hierarchical, and systematic analysis method [8]. It decomposes the indicators of a problem into three levels: the goal level, criterion level, and alternative level. Finally, subjective ranking is conducted based on the superiority or inferiority of each indicator to obtain the importance weights of the indicators. The main steps involved are as follows: (1) Establishing a hierarchical structure model. (2) Constructing judgment (pairwise comparison) matrices. (3) Conducting individual ranking and consistency testing. (4) Conducting overall ranking and consistency testing.

2.3.2 Entropy weighting method

The Entropy Weight Method belongs to the objective weighting method and is a weighting method that determines the weights of indicators by calculating the information entropy of each indicator and evaluating the relative impact of each indicator on the overall system [9]. If the entropy of an indicator is smaller, it indicates a higher degree of variation in the indicator and provides more information, resulting in a larger weight. Conversely, if the entropy of an indicator is larger, its weight is smaller. The main steps involved are as follows: (1) Constructing the decision matrix. (2) Normalizing the indicators. (3) Calculating the information entropy of the indicators. (4) Calculating the coefficient of variation and weight coefficients for the indicators.

2.3.3 Game theory combination weighting model

The Game Theory Combination Weighting Method is widely used in security system evaluation. In order to seek the optimal solution for the overall benefit of the target system, the game theory assumes that each alternative is the result of rational decision-making. Therefore, the final outcome is achieved through the collective efforts of all decision-makers [10].

Let's denote the weight vectors obtained from the analytic hierarchy process and the entropy weighting method as w_1, w_2. We can perform an arbitrary linear combination of the two weight vectors, using linear combination coefficients denoted as α_1, α_2. The goal is to optimize α_1, α_2 to minimize the deviation between w and w_1, w_2:

$$\min \sum_{i=1}^{2} (\alpha_i w_i^{\mathrm{T}} - w_i) \tag{1}$$

Taking the first-order derivative of the equation (1) based on the different coefficients, we can derive the optimal values:

$$\begin{pmatrix} w_1 w_1^{\mathrm{T}} & w_1 w_2^{\mathrm{T}} \\ w_2 w_1^{\mathrm{T}} & w_2 w_2^{\mathrm{T}} \end{pmatrix} \begin{pmatrix} \alpha_1 \\ \alpha_2 \end{pmatrix} = \begin{pmatrix} w_1 w_1^{\mathrm{T}} \\ w_2 w_2^{\mathrm{T}} \end{pmatrix} \tag{2}$$

Solving these equations will give us the optimal coefficients, we can normalize them to obtain the weight optimal distribution ratio coefficients.

2.4 Particle swarm optimization projection pursuit evaluation model

The projection pursuit evaluation (PPE) method is an efficient statistical approach for dealing with multi-factor complicated problems, and it may be immediately applied to nonlinear and non-normal issues. Its primary premise is to project high-dimensional data into low-dimensional space in a certain combination, and by determining the best projection value, the evaluation value achieved is more referential. The particle swarm optimization (PSO) algorithm is primarily based on adaptive weight computation, which is integrated with the history and present ideal individual location, and it gradually approaches the optimal. We employ a novel algorithm, the PSO-PPE model. This approach combines the PSO algorithm and PPE method, which not only speeds up PSO convergence but also solves the problem of discrete random variables [11].

The objective function of the PSO-PPE model is as follows:

$$\max Q(A) = S_Z \cdot D_Z$$
$$s.t. \begin{cases} A > 0 \\ \sum_{j=1}^{m} a_j^2 = 1, -1 < a_j < 1 \end{cases} \tag{3}$$

$$\begin{cases} S_Z = \sqrt{\dfrac{1}{n-1} \sum_{i=1}^{n} (z_i - \bar{z})^2} \\ D_Z = \sum_{i=1}^{n} \sum_{j=1}^{m} (R - r_{ij}) \cdot I(R - r_{ij}) \end{cases} \tag{4}$$

Where S_Z represents the sample standard deviation of the projection eigenvalues, where a higher value indicates a more uniform distribution of the sample data. D_Z represents the local density of the projection eigenvalues. The value of the window radius R for the local density depends on the structure of the sample data. r_{ij} represents the distance between the projection eigenvalues, and $I(R-r_{ij})$ is the unit step function.

2.5 Coupling coordination model

The coupling coordination model is used to analyse the interconnectedness and level of coordinated development between systems or entities. This model primarily focuses on the degree of coupling and coordination among various components and evaluates the interactions and synergies between them using quantitative indicators [12]. Therefore, this model can provide a better measurement and visualization of the level of coordination between the electrification development of urban new energy electric vehicles and the ecological environment.

The calculation formula is as follows:

$$C = \sqrt{\frac{S_1 \times S_2}{\sqrt{\frac{1}{2}(S_1 + S_2)}}} \tag{5}$$

$$T = \alpha_1 S_1 + \alpha_2 S_2 \tag{6}$$

$$D = \sqrt{C \times T} \tag{7}$$

Where C is the coupling degree. S_1, S_2 represent the new energy electric vehicle development index and ecological environment index respectively. The larger the value of C is, the smaller the degree of dispersion between the subsystems is, the higher the degree of coupling is. On the contrary, the lower the degree of coupling between the subsystems is. T is the comprehensive coordination index. α_1, α_2 is the importance of the two respectively, and each of them is taken as 0.5 here. D is the coupling coordination degree, the value range is [0, 1]. The higher the value of D, the higher the degree of coupling coordination, the more coordinated the development of the two systems, and vice versa, the worse.

Comparing the calculated coupling coordination degree D value with the predefined division criteria to classify the system into different coordination levels, the coordination development level of the system can be understood more intuitively, as shown in Table 3.

Table 3. Classification of different types of coupling coordination.

Coordination degree	Coupling coordination degree	Coordination type
Dysfunctional recession period	[0.0, 0.2]	Severe disorder
	[0.2, 0.4]	Mildly dysfunctional
Transition period	[0.4, 0.6]	Primary coordination
Harmonization period	[0.6, 0.8]	Intermediate coordination
	[0.8, 1.0]	Good coordination

3 Result

We programmed the MATLAB software to solve the coupled and coordinated development model of new energy electric vehicles and ecological environment in China, and the results are shown in Figure 1.

 https://doi.org/10.1051/e3sconf/202452004012

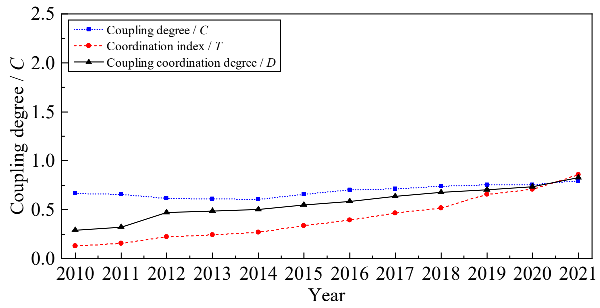

Fig. 1. Coupling coordination degree model result.

It can be visualized from Figure 10 that the coupling degree (*C*), coordination index (*T*) and coupling coordination degree (*D*) of China's new energy electric vehicle development and the ecological environment show an overall increasing trend. Among them, the coupling degree (blue dotted line) rises slowly from 0.667 in 2010 to 0.797 in 2021. the coordination index (red dotted line) rises rapidly from 0.127 in 2010 to 0.859 in 2021. The coupling coordination degree (black solid line) is a combination of the coupling degree and coordination index, reflecting the overall "efficacy" and "synergy" effect between the two systems, which can be used to analyse the level of coordinated development.

In the figure, the coupling degree of coordination gradually increases from 0.292 in 2010 to 0.828 in 2021, and combined with Table 2, the two systems are in a period of dysfunctional decline in 2010-2012, in a period of transition in 2013-2016, and in a period of coordinated development in 2017-2020. development period. It can be seen that the impact of the development of new energy electric vehicles on the ecological environment in China presents a positive and positive development year by year.

4 Conclusion

This paper introduces a coupled coordinated development model to analyse the coupling relationship and degree of coordination between new energy electric vehicles and the ecological environment in China. Based on the results and discussions presented above, the conclusions are obtained as below:

(1) We constructed a new energy vehicle development and ecological environment level evaluation index system containing 15 and 20 indicators respectively, and realized the level evaluation of China's new energy vehicle development and ecological environment based on the game theory combination empowerment method and the particle swarm optimization projection tracing evaluation model.

(2) We introduce a coupled coordinated development model to analyse the degree of coupled coordination between new energy electric vehicles and the ecological environment in China. The results show that the coupling degree of coordination gradually increases from 0.292 in 2010 to 0.828 in 2021, and the impact of the development of new energy electric vehicles on the ecological environment in China presents a positive and positive development year by year.

References

1. I. S. Sorlei, N. Bizon, P. Thounthong, M. Varlam, E. Carcadea, M. Culcer, M. Raceanu, Fuel cell electric vehicles-A brief review of current topologies and energy management strategies, Energies, **14**, 252 (2021)
2. J. Pu, W. Chun, Z. Wang, W. Chen, Operation strategy for new energy vehicle enterprises based on dual credit policy, J. Ind. Manag. Optim **19**, 5724-5748 (2023)
3. K. Sim, S.H. Hwang, A Control Algorithm of an Idle Stop and Go System with Traffic Conditions for Hybrid Electric Vehicles, IEEE T. Intell. Transp **23**, 14427-14438 (2021)
4. D. Cui, Z. Wang, P. Liu, S. Wang, Z. Zhang, D.G. Dorrell, X. Li, Battery electric vehicle usage pattern analysis driven by massive real-world data, Energy, **250**, 123837 (2022)
5. A. König, L. Nicoletti, D. Schröder, S. Wolff, A. Waclaw, M. Lienkamp, An overview of parameter and cost for battery electric vehicles, World Electric Vehicle Journal, **12**, 21 (2021)
6. Z. Lin, X. Sun, Y. Ji, Landslide displacement prediction based on time series analysis and double-BiLSTM model, Int. J. Env. Res. Pub. He **19**, 2077 (2022)
7. H. Li, Y. Liu, X. Luo, H. Duan, A novel nonlinear multivariable Verhulst grey prediction model: A case study of oil consumption forecasting in China, Energy Rep **8**, 3424-3436 (2022)
8. Z.H. Xu, H. Lin, J. Xu, S. Li, X. Hu, Health level assessment of residents in Fujian province based on fuzzy comprehensive evaluation model. In *2nd International Conference on Applied Mathematics, Modelling, and Intelligent Computing (CAMMIC 2022)* (Vol. 12259, pp. 833-837) (2022, May)
9. Z.H. Xu, Machine Learning-Based Quantitative Structure-Activity Relationship and ADMET Prediction Models for ERα Activity of Anti-Breast Cancer Drug Candidates, Wuhan University Journal of Natural Sciences, **28**, 257-270 (2023)
10. M. Dong, J. Cheng, L. Zhao, A combination weighting model based on iMOEA/D-DE, Front. Inform. Tech. El **23**, 604-616 (2022)
11. Z.T.M. Taher, A nonlinear system modeling method based on projection pursuit and particle swarm optimization algorithm, Int. J. Nonlinear Anal **13**, 277-283 (2022)
12. L. Chen, Y. Tan, G. Lv, W. Cai, X. Gao, Li, R. Uncovering the coupling effect with energy-related carbon emissions and human development variety in Chinese provinces, J. Environ. Sci **139**, 527-542 (2024)