Journal of Innovation and Development
ISSN: 2958-4752 | Vol. 3, No. 1, 2023

Research on Coordinated Development of Energy Internet and Energy Transition

Jun Zhang *

School of Economics and Management, Southwest Petroleum University, Chengdu 610500, China

Abstract: This paper explores the coupling and coordinated relationship between the development of Energy Internet and Energy Transition. Based on the evaluation index system of coupling and coordinated development between the Energy Internet and Energy Transition, this paper analyzes and evaluates the relevant data of China from 2011 to 2020. The research results show that the comprehensive development evaluation value of the Energy Internet is higher than that of Energy Transition, and the development effect of the Energy Internet is better than that of the Energy Transition process. In the future, the comprehensive development evaluation value of the Energy Internet and Energy Transition will continue to rise, but the evaluation value of Energy Transition will fluctuate. In terms of coupling and coordination, from 2011 to 2020, the coupling degree and coordination degree of the Energy Internet and Energy Transition systems in China have shown a trend of fluctuating upward, but the fluctuation range is not large. It is expected that in the next decade, the Energy Internet and Energy Transition system in China will gradually enter a stage of coordinated development.

Keywords: Energy Internet; Energy Transition; Even and Coordinated Development.

1. Introduction

Energy issues have always been a global concern. As one of the largest energy consumers in the world, China has been actively promoting energy transformation. To address climate change, the Chinese government has proposed the goals of peaking carbon dioxide emissions around 2030 and achieving carbon neutrality around 2060, making positive contributions to global efforts in combating climate change. The Chinese government has been continuously strengthening the control of carbon emissions and gradually shifting towards renewable energy. However, due to the large energy demand, an unreasonable energy supply structure, and low energy consumption efficiency, the promotion of energy transformation and the response to climate change face severe challenges.

In this context, the Energy Internet is seen as an important way for China to promote energy transformation. The Energy Internet refers to the intelligent connection of dispersed energy supply and demand sides through digital technology and the Internet of Things (IoT), which realizes energy interconnection, sharing, and optimized allocation, thereby improving energy utilization efficiency and reducing carbon emissions. At the same time, the Energy Internet can effectively solve the problem of the volatility of renewable energy through the characteristics of multi-energy complementarity and flexible operation, further promoting the process of China's energy transformation. The construction of the Energy Internet is of great significance for the sustainable development of China's economy and society. On the one hand, the Energy Internet can improve energy supply security, achieve multi-energy complementary sharing, and reduce dependence on traditional energy, thereby improving the reliability and stability of energy supply. On the other hand, the Energy Internet can effectively reduce carbon emissions, alleviate the impact of global climate change, promote economic transformation and upgrading, improve China's energy utilization efficiency, and promote green and low-carbon development.

To achieve the goals of peaking carbon emissions and achieving carbon neutrality, the Chinese government has formulated a series of policies and measures to actively promote energy transformation and the construction of the Energy Internet. In this process, it is of great practical and strategic significance to study the coupled and coordinated development of the Energy Internet and energy transformation, explore their roles and values in promoting China's carbon emission reduction and achieving sustainable economic development. Therefore, this paper will focus on the relationship between the Energy Internet and energy transformation, and explore their roles and values in promoting peaking carbon emissions and achieving carbon neutrality. This paper will review the development status of the Energy Internet, analyze its applications and roles in energy transformation, and provide valuable references for the sustainable development of China's energy sector.

2. Literature Review

Energy Internet refers to the integration of dispersed and diversified energy resources through intelligent interconnection to form a complementary energy system, in order to improve energy efficiency, reduce energy consumption and carbon emissions, and achieve the upgrading and transformation of the energy structure. The concept of Energy Internet has been widely recognized and supported globally.

(1) The Development Process of Energy Internet

①World Energy Internet

The concept of world energy internet originated from the "energy transition" strategy proposed by Germany. In 2011, the German government put forward the initiative of "energy transition", aiming to gradually reduce the use of fossil energy, promote the development and utilization of renewable energy. To achieve this goal, the German government actively promoted the construction of smart grids and the transformation and upgrading of the power system. With the continuous development and application of smart grid technology, the concept of energy internet began to be gradually proposed and explored. In 2014, the European Union proposed the "Energy Union Plan", aiming to build an energy internet within the European Union to achieve the exchange and sharing of clean energy. In 2015, the US Department of Energy released the "Energy Internet Plan", which proposed the goals and plans for building smart grids and energy internet in the next decade. In 2016, China put forward the "Belt and Road" initiative, advocating the construction of "energy internet" to promote the sharing and exchange of international clean energy. Internationally, the development of energy internet has been increasingly valued and supported by more and more countries. Developed countries such as the European Union, the United States, and Japan actively promote the construction of smart grids and energy internet to improve energy utilization efficiency and reduce carbon emissions. At the same time, some developing countries have also begun to explore and try to build energy internet to promote sustainable development of energy and economic growth.

②Chinese Energy Internet

The concept of energy internet originated from 2009 when Jiang Zhiyun, an academician of the Chinese Academy of Sciences, proposed the concept of "energy internet" while researching energy system optimization. With the continuous development and application of technology, energy internet has gradually become a hot issue of concern for scholars and governments at home and abroad. In 2015, the National Energy Administration of China issued the "Implementation Opinions on Building Energy Internet and Accelerating Energy Transformation", proposing the guiding principles and implementation paths for energy internet construction. In 2017, the National Energy Administration of China also established energy internet pilot zones nationwide to explore the experience and models of energy internet construction and application.

(2) Relevant research by domestic and foreign scholars

In recent years, domestic scholars have carried out a large amount of research in the field of energy internet, including scientific research projects, papers, and experimental areas. For example, the Chinese Academy of Sciences launched the "Global Energy Internet Development Strategy Study" project, which studies the development trends and technological routes of the global energy internet. At the same time, many universities and research institutions in China have also conducted related research in the field of energy internet, such as Tsinghua University, the China Electric Power Research Institute, the State Grid Electric Power Research Institute, etc.

In foreign countries, organizations such as the European Commission and the International Energy Agency have also carried out a large amount of research in the field of energy internet. For example, the European Commission proposed the concept of "European Energy Internet" in 2016 to establish a transnational energy internet system to improve energy reliability and security. At the same time, countries such as Germany, Sweden, and Finland are also promoting the testing and construction of energy internet.

Zhao Liang et al. (2016) studied the construction and operation mechanism of energy internet, and proposed the advantages and challenges of energy internet in energy supply-demand balance, energy consumption management, and the development and utilization of new energy. Chen Hongsong et al. (2017) studied the energy internet technology based on cloud computing and big data, and proposed the application and development of energy internet in energy management, energy trading, and energy security. Koirala et al. (2018) studied the relationship between smart grids and energy internet, analyzed their advantages and limitations in energy production, transmission, and usage, and proposed the feasibility and development direction of combining smart grids and energy internet. Wang Ruiling et al. (2019) studied the coordinated development of energy internet and energy transition, proposed policy support and technological innovation for the construction of energy internet to promote energy transition and sustainable development. Zhang Cheng et al. (2020) studied the feasibility and economic benefits of regional energy internet, established evaluation indicators and models of regional energy internet using system dynamics, and evaluated its comprehensive benefits and sustainability in economic, environmental, and social aspects. Li Jianhua et al. (2021) studied the construction path and technological innovation of urban energy internet, proposed a multi-level and diversified development model of urban energy internet, and analyzed the technical, policy, and market risks it faces.

In summary, the research on energy internet involves a wide range of fields, including energy systems, information technology, economics, environmental science, and so on. With the continuous promotion of the construction of energy internet, related research will continue to deepen and expand.

(3) Future Development Direction

Based on the development process of the energy internet and the relevant research of scholars at home and abroad, it can be foreseen that the future energy internet will deeply develop in the following aspects:

Firstly, technological innovation. With the application of new technologies such as artificial intelligence and the Internet of Things, the energy internet will continue to realize intelligence, automation, and digitization, thereby achieving more efficient, reliable, and secure energy management and dispatch.

Secondly, multi-energy complementarity. The energy internet will continue to expand the scope of energy complementarity, including the utilization of various types of energy such as wind energy, solar energy, and hydropower to achieve more stable and sustainable energy supply.

Thirdly, cross-regional cooperation. The construction of the energy internet needs to cross different geographical regions and political boundaries. Therefore, future development needs to strengthen international cooperation and communication, establish cross-border energy internet systems to achieve the sustainable development of global energy.

Fourthly, carbon neutrality. The construction of the energy internet is one of the important ways to achieve carbon neutrality goals. In the future, the energy internet will continue to promote the application of clean energy and reduce carbon emissions to achieve the goal of carbon neutrality.

3. Coupled Coordination Analysis of Energy Internet and Energy Transformation

(1) Theoretical Model

According to the viewpoint of synergy, although different systems have different properties, there are mutual influence and cooperation relationships among various systems in the entire environment. This includes typical social phenomena, such as the coordination and cooperation among different units, the coordination of relationships between departments, the role of mutual competition among enterprises, and the mutual interference and restraint in the system. There is an obvious mutual influence relationship between the development system of the energy internet and the energy transformation system, but further exploration of the relationship between the two requires quantitative analysis. The coupled coordination model can measure the inherent relationship between the development of the energy internet and energy transformation, clearly describe the interaction and influence degree between systems, reflect the overall structural function of the system, and analyze the influence degree of each element in the system on the overall development level.

①Normalization

Due to the existence of different dimensions and units among indicators, it is necessary to normalize the indicators. According to the different attributes of indicators, they can be divided into positive indicators, which indicate that the larger the value, the more advanced the system development, and negative indicators, which indicate that the larger the value, the more backward the system development. Let Z_{ijt} be the standardized value of the jth indicator of the ith system in the tth year; $max(Y_{ijt})$ be the maximum value of the jth indicator of the ith system; and $min(Y_{ijt})$ be the minimum value of the jth indicator of the ith system. For positive indicators, the calculation formula of the standardized value is:

$$Z_{ijt} = \frac{Y_{ijt} - \min(Y_{ijt})}{\max(Y_{ijt}) - \min(Y_{ijt})}$$

For negative indicators, the calculation formula of the standardized value is:

$$Z_{ijt} = \frac{\max(Y_{ijt}) - Y_{ijt}}{\max(Y_{ijt}) - \min(Y_{ijt})}$$

After standardizing the indicator values, the indicators across regions and years become comparable and the differences in magnitude and direction between the original indicators can be eliminated. In addition, to make data calculations meaningful, zero values must be eliminated, but the inherent patterns of the dimensionless data after standardization must be preserved. Therefore, a slight adjustment is made to the standardized values, namely $Z_{ijt} = Z_{ijt} \times 0.9 + 0.1$, to be used as the new standard values.

②Indicator weights

This section uses the entropy method to determine the weights of each indicator. In information theory, entropy is a method of measuring uncertainty. More information can reduce uncertainty and entropy; less information leads to greater uncertainty and therefore greater entropy. Starting from the properties of entropy, the randomness and disorder of an event can be determined by calculating the entropy value. The entropy value can also be used to determine the degree of variation of a certain index, and the higher the variation of an index, the greater its impact on the overall evaluation. Therefore, the variation of each indicator can be determined through entropy, and the weights of each indicator can be obtained to provide reference for the comprehensive evaluation of multiple indicators.

a. Calculate the feature weight (contribution) of the indicator:

Assuming that P_{ijt} is the feature weight of the jth indicator of the ith subsystem in the tth year, the calculation formula for P_{ijt} is:

$$P_{ijt} = \frac{Z_{ijt}}{\sum Z_{ijt}}$$

b. Calculate the entropy value:

Assuming that e_{ij} is the entropy value of the jth indicator of the ith subsystem, the calculation formula for e_{ij} is:

$$e_{ij} = -\frac{1}{lnn} \sum_{i=1,j=1}^{n} P_{ij}(lnP_{ij})$$

c. Calculate the coefficient of variation:

Assuming that g_{ij} is the coefficient of variation of the jth indicator of the ith subsystem, the calculation formula for g_{ij} is:

$$g_{ij} = 1 - e_{ij}$$

d. Calculate the weight of the indicator:

Assuming that W_{ij} is the weight of the jth indicator of the ith subsystem, the calculation formula for W_{ij} is:

$$W_{ij} = \frac{g_{ij}}{\sum g_{ij}}$$

③Subsystem Comprehensive Evaluation Model

After obtaining the weights W_{ij} of each index in each subsystem based on the entropy method, the comprehensive evaluation value of each subsystem can be calculated by using the weights and the standardized values of each index. This value is also called the effectiveness index of the subsystem, which reflects the comprehensive consideration of the subsystem. Assuming U_{it} is the comprehensive evaluation value of the i-th subsystem in the t-th year, its calculation formula is:

$$U_{it} = \sum W_{ij} \times Z_{ijt}$$

④Coupling and Coordination Model

This section measures the degree of coupling between the energy internet development and energy transition systems using the following formula:

$$C_t = \left[\frac{\prod_{i=1}^{n} U_{it}}{(\frac{1}{n}\sum_{i=1}^{n} U_{it})^n}\right]^{\frac{1}{n}}$$

Where C_t is the coupling degree of the energy internet development and energy transition system in year t, and its value ranges from [0, 1]; n is the number of subsystems.

The coupling degree is used to measure the level of interaction between subsystems. Different coupling degrees represent different levels of interaction between subsystems. According to the size of the coupling degree, this article divides the coupling degree level of the energy internet development and energy transition system into several stages, as shown in the following table:

Table 1. Classification standards for coupling stages

Coupling degree C	Coupling stage
[0, 0.3)	Low-coupling stage
[0.3, 0.5)	Antagonistic stage
[0.5, 0.8)	Cohesion stage
[0.8, 1.0]	Coordinated stage

Although the coupling degree model can reflect the degree of interaction between the energy internet development system and the energy transformation system, it cannot reflect whether the systems are mutually promoting or restricting each other at a high or low level. To solve this problem, this chapter constructs a coupling coordination model based on the coupling degree model. Assuming that D_t is the coupling coordination degree of the energy internet development and energy transformation system, D_t ranges from 0 to 1, and the calculation formula is:

$$D_t = \sqrt{C_t \times T_i}$$

Where T_i is the comprehensive coordination index of the i-th system, which is assigned according to the contribution of different subsystems to the total system. For two systems, their contributions to the total system are equally important, and this chapter takes $T_1 = T_2 = 1/2$.

Similarly, it is necessary to divide the coupling coordination degree level D_t to represent the coordinated development stages of the energy internet development and energy transformation. The specific classification standards are shown in Table 2.

Table 2. Coupling Coordination Stage Classification Criteria

Coupling Coordination D	Coordination Development Stage
[0, 0.1)	Extreme Imbalance
[0.1, 0.2)	Severe Imbalance
[0.2, 0.3)	Moderate Imbalance
[0.3, 0.4)	Slight Imbalance
[0.4, 0.5)	Borderline Imbalance
[0.5, 0.6)	Barely Coordinated
[0.6, 0.7)	Primary Coordination
[0.7, 0.8)	Intermediate Coordination
[0.8, 0.9)	Good Coordination
[0.9, 1.0]	Excellent Coordination

(2) Construction of Indicator System

To comprehensively and fully reflect the coupling and coordination relationship between the development of energy internet and energy transformation, this section constructs an evaluation indicator system for the coupling and coordinated development of the development of energy internet and energy transformation as shown in the table below.

The energy internet and energy transformation system include two subsystems: the development of energy internet and energy transformation. The development of energy internet subsystem mainly includes three primary indicators: technology, investment, and electricity development. Regarding technology, the energy internet is a product of the combination of modern information technology and energy technology, such as IoT technology, clean energy utilization technology, UHV transmission technology, etc., which are the foundation for promoting the development of energy internet. A country's technological development is mainly influenced by R&D personnel (referring to personnel engaged in basic research, applied research, and experimental development activities in the reporting period of R&D activity units) and R&D expenditure. In addition, the research results of many scholars have shown a significant relationship between a country's technological development level and its GDP. Generally, the higher the proportion of R&D investment in GDP, the higher the country's technological level. Therefore, when constructing the indicator system, this section takes the proportion of R&D expenditure to GDP as an important secondary indicator to measure the primary technology indicator along with R&D personnel and R&D expenditure.

Regarding investment, the energy internet emphasizes multi-energy complementarity, but electricity is currently the most advantageous secondary energy for developing the energy internet. Converting various primary energies into electricity through a multi-energy complementary system and transporting and storing them is the basic consensus for developing the energy internet at this stage. Therefore, electricity investment is a crucial factor influencing the development of the energy internet. The larger the amount of electricity investment, the stronger the impetus to promote the development of the power industry, thereby driving the development of the energy internet. Energy industry investment refers to the funds invested by the country in the entire energy industry. In addition to electricity investment, energy industry investment is also essential for developing the energy internet. Energy industry investment can promote the construction of the country's energy infrastructure and the development of various energy technologies, laying a solid foundation for developing the energy internet.

Regarding the electricity development situation, the electricity development situation plays a crucial role in promoting the development of the energy internet. The electricity network is currently the energy network with the highest coverage and minimum transmission loss in China. According to the latest data from the State Grid, China's electricity network coverage rate is as high as 99.03%, and the transmission loss is about 6.5%, maintaining a transmission efficiency of around 95%. However, currently, there are still situations such as low integration level of power grids between regions, inability to meet local power demand with local power generation, and low per capita electricity consumption in China. In addition, most scholars' research shows that electricity development is closely related to GDP. Based on this, generating capacity, per capita electricity usage, and electricity consumption per 10,000 yuan of GDP are taken as the secondary indicators of electricity development to comprehensively examine China's electricity development situation.

The energy transition system includes three primary indicators: development status, clean energy, and market size. Regarding the development status, the main secondary indicators selected are the proportion of clean energy consumption and fossil fuel consumption. An important criterion for the success of energy transition is whether clean energy consumption dominates the energy consumption structure. Therefore, the higher the proportion of clean energy consumption, the greater the achievements of energy transition. On the other hand, the proportion of fossil fuel consumption can be used as a reverse indicator, indicating the development status of energy transition. The higher the proportion of fossil fuel consumption, the less ideal the current state of energy transition. Conversely, the lower the proportion of fossil fuel consumption, the better the development status of energy transition.

As for clean energy, nuclear power and wind power are the two clean energy sources with the highest utilization rate in China. According to the data from the National Energy Administration, as of the end of 2021, China's wind power installed capacity was about 330 million kilowatts, a year-on-year increase of 16.6%. According to data from the National Nuclear Safety Administration, as of December 31, 2021, China has a total of 53 operating nuclear power units (excluding Taiwan), with an installed capacity of 54,646.95 MWe (rated installed capacity). Based on this, using nuclear power and wind power as secondary indicators can comprehensively examine the development of China's clean energy.

Regarding the market size, the main secondary indicators selected are environmental governance investment, the proportion of non-fossil energy generation, and the proportion of fossil fuel power generation installed capacity. Some of the funds from environmental governance investment will be used to control the pollutants generated during energy production, consumption, infrastructure construction, and energy technology research. Additionally, new environmental protection technologies developed through environmental governance investment can also be directly used for clean energy utilization. Therefore, environmental governance investment is a positive indicator for energy transition. The higher the proportion of non-fossil energy generation, the larger the market size of clean energy, making it a positive indicator. At present, the technology level cannot achieve complete clean utilization of fossil fuels, so the corresponding installed capacity of fossil fuel power generation is a negative indicator. Environmental governance investment, the proportion of non-fossil energy generation, and the proportion of fossil fuel power generation installed capacity can comprehensively examine the market size of energy transition.

Table 3. Energy Internet development and energy transition even and coordinated development evaluation index system construction

Subsystem	Primary indicator	Secondary indicator	Variable	Unit	Direction
Energy Internet Development	Technology	R&D personnel	Y_{11}	million	+
		R&D expenditure	Y_{12}	billion yuan	+
		R&D expenditure in proportion to GDP	Y_{13}		+
		Patent Inventions	Y_{14}	pieces	+
	Investment	Electricity Investment	Y_{15}	billion yuan	+
		Energy Industry Investment	Y_{16}	billion yuan	+
	Power Development	Electricity generation	Y_{17}	Billion kWh	+
		Per capita usage	Y_{18}	kWh	+
		Electricity consumption of 10,000 Yuan GDP	Y_{19}	tec/yuan	+
Energy transition	Development Status	The proportion of clean energy consumption	Y_{21}		+
		The proportion of fossil energy consumption	Y_{22}		-
	Clean Energy	Nuclear power	Y_{23}	Billion kWh	+
		Wind power	Y_{24}	Billion kWh	+
	Market Scale	Investment in environmental management	Y_{25}	billion	+
		Share of non-fossil energy power generation	Y_{26}		+
		Percentage of installed fossil energy generation capacity	Y_{27}		-

(3) Coupling coordination degree measurement and analysis

In this section, based on the evaluation index system of coupled and coordinated development of energy Internet development and energy transformation, the relevant data of China from 2011 to 2020 are selected, and based on the above theoretical model, the calculated comprehensive development evaluation value of the two subsystems of energy Internet development and energy transformation is shown in Table 4, and the calculated coupled and coordinated degree of energy Internet development and energy transformation is shown in Table 5, the development trend of energy Internet development and energy transformation is shown in Figure 1, and the development trend of coupled and coordinated development of energy Internet development and energy transformation is shown in Figure 2. The development trend of comprehensive development evaluation value of energy Internet development and energy transformation is shown in Figure 1, and the development trend of coupling and coordination of energy Internet development and energy transformation is shown in Figure 2.

From the comprehensive development evaluation value of energy Internet development and energy transition, it can be seen that the comprehensive development evaluation value of energy Internet is higher than energy transition in all years, indicating that the development effect of energy Internet is better than the energy transition process, and energy transition is influenced by energy Internet development and other factors at the same time, but energy Internet development is the most critical factor. As shown by the development trend of comprehensive development evaluation value of energy Internet development and energy transformation, the comprehensive development evaluation value of energy Internet development in the past ten years shows a steady rising trend, indicating that the development of China's energy Internet is more stable, and after ten years of development, its comprehensive evaluation value rises from 0.1079 in 2011 to 0.4683 in 2020; the comprehensive development evaluation value of energy transformation in the past ten years The first peak occurred in 2013, and the trough occurred in the following year; the second peak occurred in 2017, and the trough also occurred in the following year. The main reason for the fluctuating rise in the evaluation value of the comprehensive development of energy transition is that the transition is influenced by a variety of factors and needs to touch the interests of many parties, so there are multiple peaks and valleys in line with the reality. It is expected that the comprehensive development evaluation value of China's energy Internet development and energy transition will continue to rise in the future, but the evaluation value of energy transition will also fluctuate.

From the calculation results of the coupling and coordination relationship between energy Internet development and energy transition, it can be seen that from 2011 to 2020, the coupling degree of China's energy Internet development and energy transition system are lower than the coordination degree, and after 2015, the coupling degree exceeds the coordination degree. From the graph of the coupling and coordination development trend of energy Internet development and energy transition, it can be seen that the coupling degree and coordination degree of energy Internet development and energy transition system both show a fluctuating upward trend from 2011 to 2020, but the fluctuation is not large. 2011-2020, the coupling and coordination relationship of China's energy Internet development and energy transition can be divided according to the standard table of coupling and coordination stages into The first stage is the mild dissonance stage from 2011 to 2012, in which the mutual promotion between China's energy Internet development and energy transition is not obvious and there is a certain degree of dissonance, and the two have not formed a coordinated development; the second stage is the near dissonance stage from 2013 to 2015, in which the dissonance between the two has increased compared with the previous stage. In the third phase, i.e., 2016-2020, the energy Internet development and energy transition system entered a barely coordinated phase, and the two began to promote each other, but the mutual promotion role is still in the primary stage. However, it is expected that in the next decade, China's energy Internet development and energy transition system will develop from the barely coordinated stage to the well-coordinated stage.

Table 4. Integrated development evaluation value of energy Internet development and energy transition

Year	Energy Internet Development	Energy Transformation
2011	0.1079	0.0840
2012	0.1543	0.0687
2013	0.2088	0.1369
2014	0.2334	0.1199
2015	0.2790	0.1967
2016	0.3417	0.2353
2017	0.3856	0.3305
2018	0.4029	0.3136
2019	0.4490	0.3854
2020	0.4683	0.4491

Table 5. Calculation results of coupled coordination relationship between energy internet development and energy transition

Year	Coupling Degree	Coordination Degree	Coordination Stage
2011	0.3074	0.3921	Slightly Imbalanced
2012	0.3083	0.3926	Slightly Imbalanced
2013	0.4066	0.4509	Imminent Imbalance
2014	0.3981	0.4461	Imminent Imbalance
2015	0.4804	0.4901	Imminent Imbalance
2016	0.5279	0.5138	Barely Coordinated
2017	0.5966	0.5462	Barely Coordinated
2018	0.5939	0.5449	Barely Coordinated
2019	0.6440	0.5675	Barely Coordinated
2020	0.6771	0.5819	Barely Coordinated

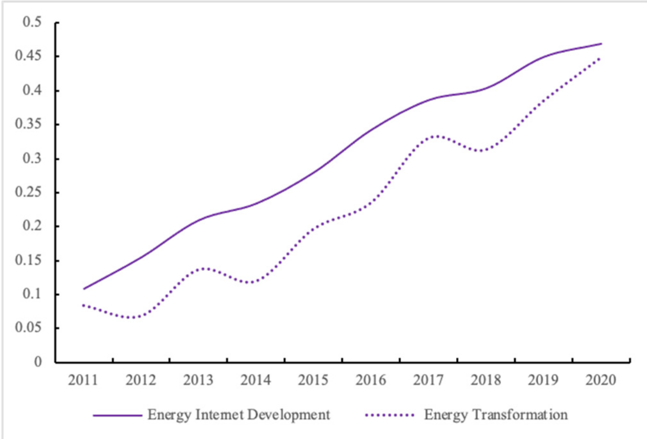

Figure 1. Energy Internet development and energy transition comprehensive development evaluation value development trend

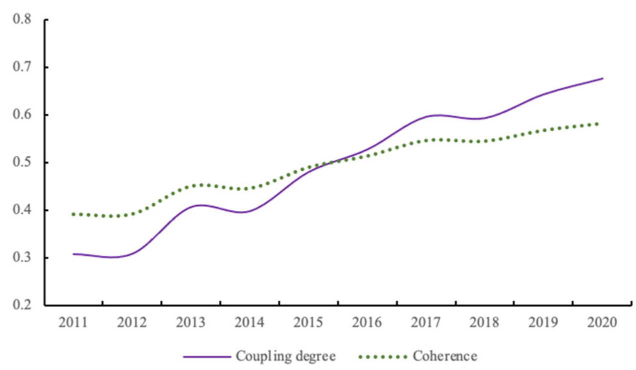

Figure 2. Development trend of coupling and coordination between energy internet development and energy transition

4. Conclusion and Recommendations

(1) Research Conclusion

The research results of this paper show that the development effect of China's energy Internet is better than that of the energy transition process. The comprehensive development evaluation value of the energy Internet shows a steady upward trend during 2011-2020, while the comprehensive development evaluation value of the energy transition shows a fluctuating upward trend, and there are two peaks and valleys. It is expected that the comprehensive development evaluation value of China's energy Internet development and energy transition will continue to rise in the future, but the evaluation value of energy transition will also fluctuate. Regarding the coupling and coordination relationship between energy Internet development and energy transition, the coupling degree of China's energy Internet development and energy transition system were lower than the coordination degree from 2011 to 2020, but since 2015, the coupling degree has exceeded the coordination degree. It is expected that in the next decade, China's energy Internet development and energy transition system will gradually enter the stage of coordinated development.

(2) Recommendations

The findings show that the comprehensive development evaluation value of energy Internet development in China has steadily increased, and the comprehensive development evaluation value of energy transition has fluctuated. At the same time, the coupling coordination of energy Internet development and energy transition also shows a fluctuating upward trend, but the fluctuation is not large, and it is currently at the stage of barely coordination. Based on the conclusions, the following recommendations are made:

①Strengthen the development of energy Internet, explore more clean energy technologies, accelerate the process of energy transition, and realize the benign interaction between energy Internet and energy transition. At the same time, attention should be paid to the fluctuating upward trend of energy transition, strengthen the research on its influencing factors, and formulate corresponding policies and measures to cope with it.

②Further improve the coupling and coordination of energy Internet and energy transformation, accelerate the mutual promotion of energy Internet and energy transformation, and promote the coordinated development of both. Specifically, it can strengthen the construction of energy Internet, promote the deep integration of energy Internet and energy transition technologies, and facilitate the exchange and cooperation of energy transition practices in different regions.

③Continue to monitor and evaluate the comprehensive development evaluation value and coupling coordination degree of energy Internet and energy transition, and grasp the development dynamics and changing trends of both in time to provide scientific basis for policy formulation and decision making. At the same time, data sharing and exchange should be strengthened to promote collaborative innovation and common development in the energy field.

References

[1] Yuan Jianzhong, Ma Shengli, Li Guanghui. Energy Internet: Concept, Technology and Prospects[J]. China Engineering Science, 2017, 19(3): 32-39.

[2] Liu DJ, Chen B, Wang YX. Energy Internet: technology evolution, application status and outlook[J]. Power Grid Technology, 2020, 44(1): 1-10.

[3] Yang, L., Li, J., Huang, Y., & Song, J. (2021). Opportunities and challenges for energy internet development in China. energy Policy, 157, 112556.

[4] Zhu, Y., Lü, J., Liu, J., Huang, Q., & Du, J. (2019). Development trend of energy internet and its impact on energy security in China. Renewable and Sustainable Energy Reviews, 113, 109246.

[5] Ke, Z. D., Hu, J. H., Yuan, J. C. Research on multi-energy complementary energy supply strategy based on regional energy internet[J]. Renewable Energy, 2021, 39(4): 537-544.

[6] Li, L., Li, W., Li, J., & Xu, L. (2019). Energy internet: an overview of key technologies, applications, and challenges. IEEE Access, 7, 4521-4539.

[7] Wang, X., Wang, Y., & Xiong, H. (2021). The role of energy internet in carbon neutral transition: Evidence from China. Renewable and Sustainable Energy Reviews, 148, 111426.

[8] Zhao, J.J., Chen, B., Wang, Y. X.. Applications and challenges of energy internet in the energy sector[J]. China Energy, 2020, 42(7): 22-28.

[9] Zhang, X., Ma, Z., & Chen, Q. (2020). Inter-provincial energy flow simulation and analysis for regional energy internet planning in China. energy Policy, 146, 111878.

[10] Zhang, Z., Xue, S., & Zhou, X. (2021). A review on the applications of energy internet in energy systems. Renewable and Sustainable Energy Reviews, 150, 111457.