Research on Competitiveness Model of the Global Energy and Power Interconnection

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Abstract: The global energy and power interconnection has great significance in achieving optimal allocation of global energy resources. To quantify the demand of long-distance transmissions in various areas, this paper proposes an assessing model for the competitiveness model of the global energy and power interconnection. This quantified model is established from the physical and mathematical levels, to fully reflect the complexity and difficulty of energy and power interconnection system, a new combination weighting approach consists both of fuzzy-logarithmic and anti-entropy methods is adopted, meanwhile fuzzy membership concept is introduced into overall evaluation for Belt and Road energy and power interconnection.

1 INTRODUCTION

In order to alleviate the crisis of global energy resources, and eliminate the environmental pollution caused by fossil energy consumption, China has promoted the construction of global energy and power interconnection (Liu, 2016; Guan, 2016; Xia, 2016). Current practices in global energy and power interconnection are still in the start-up step, lack of systematic methods and tools for quantitative assessment. In terms of research considerations, most of the existing studies do not have sufficient depth of comprehensive analysis of influencing factors, focusing on the simple synthesis of energy and power resource conditions and project economy, lack of consideration of important factors such as economic and environment (Karunanithi, 2017; Kim, 2016; Wei, 2016). In terms of research methods, the existing research is based on a simple and intuitive subjective evaluation system, which makes it difficult to fully reflect the complexity of the energy and power system (Xing, 2017; Liang, 2018). Therefore, establishing a scientific and reasonable quantitative model and assessing system for the competitiveness of the global energy and power interconnection, will provide decision-making reference for the construction of energy and power interconnection in the Belt and Road.

2 ASSESSING MODEL FOR THE COMPETITIVENESS OF ENERGY AND POWER INTERCONNECTION

2.1 Physical Model

In the physical model, the factors influencing the development of energy and electric power are classified and sorted, and the key influencing factors of optimal competitiveness of energy and power interconnection are extracted from the target layer, object layer, control layer and index layer. The target layer describes the main tasks of the assessing model. The object layer consists of research objects, including renewable energy generation (hydropower, wind power, solar energy and other power generation) and non-renewable energy (coal, gas, nuclear, oil and electricity). A total of 12 assessing factors are selected. These factors are summarized into multiple subsystems, defined as control layers, each of which directly affects the evaluation of the object layer. At the bottom is the indicator layer, which sets specific indicators according to the different evaluation objectives of the corresponding subsystems, and are the basis for quantitative and comprehensive assessment, as shown in Figure 1.

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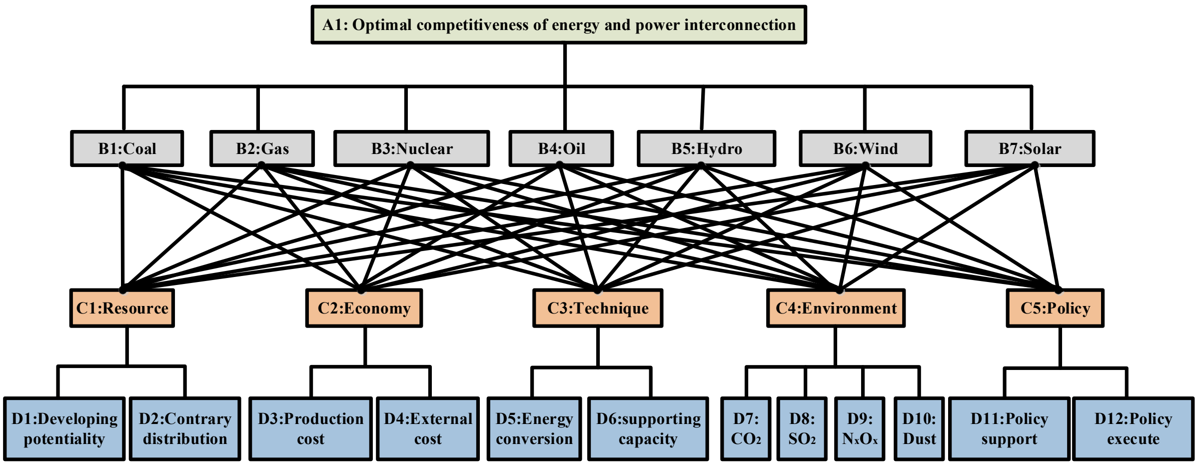

Figure 1: Physical model for the competitiveness of energy and power interconnection.

2.1.1 Resource Subsystem

In order to effectively describe the influence of resource subsystems on competitiveness of energy and power interconnection, the developing potentiality (D1) and contrary distribution (D2) are selected as the evaluation indicators under the resource subsystem. Among them, the contrary distribution refers to the distance of energy resources and load center of power generation in the regional power grid.

2.1.2 Economy Subsystem

The pursuit of economy is one of the important goals of allocation energy and power interconnection in regional power grid, and economic subsystem (C2) is mainly to depict the influence of economic factors on the power supply structure of regional power grid. The indicators reflecting the energy economy of power generation include investment cost, fuel cost, operation and maintenance cost and environmental cost, and this paper finally refines the production cost (D3) and external cost (D4) as the evaluation indicators under the economic subsystem.

2.1.3 Technique Subsystem

In this paper, the energy conversion (D5) and support capacity (D6) are set as the specific indicators of the technique subsystem (C3). The level of energy conversion is a quantitative index, characterizing the efficiency of various types of power generation technology applications, and different energy efficiency varies according to equipment level and technology level. The support capacity takes into account the average utilization coefficient of power supply, peak adjustment capacity and power generation efficiency.

2.1.4 Environment Subsystem

To depict the environmental impact of various power supplies, this section selects carbon dioxide emissions (D7), sulfur dioxide emissions (D8), nitrogen oxide emissions (D9) and dust emissions (D10) as four specific indicators under the environmental subsystems.

2.1.5 Policy Subsystem

This paper uses a policy subsystem (C5) to describe the impact of energy policies on the development of regional grid power supplies. In studying the impact of policy subsystems on power supply development, we need to consider not only the formulation (output) of energy policy, but also the effectiveness (feedback) of energy policy. Based on this, this paper uses policy support (D11) and policy execute (D12) to describe the impact of policy subsystems.

2.2 Mathematical Model

In the previous section, a physical model for the competitiveness of energy and power interconnection was established from five subsystems: resources, economy, technique, environment and policy. The content of this section is to quantify the above-mentioned physical model indicators one by one, and then build a mathematical model for the competitiveness of energy and power interconnection.

2.2.1 Indicator Layer Calculation

- Index Assignment

The first step in the calculation of the indicator layer is to assign 12 energy and power indicators, according to the nature characteristics of each indicator, this section adopts two indicator assignment methods: 1) for quantitative energy and power indicators, this paper studies literature reports issued by the authorities (including The International Energy Agency, the U.S. Energy Information Administration, BP, and Bloomberg New Energy Finance, etc.) to obtain important data information; 2) for qualitative energy and power indicators, this paper designs the indicator scoring table, which is assigned by a number of energy and power industry experience experts. Then we can get the assignment matrix $\boldsymbol{B_k}$ of the *n*th indicators of the *k*th control layer subsystem where $\boldsymbol{B_k}=[b_1, b_2,\ldots, b_n]$.

- Normalization

The second step of the calculation of the indicator layer is normalization processing: each energy and power indicator has different physical significance and value range, in order to enable it to carry out comprehensive analysis, it is necessary to normalize so that the energy and power indicators have a consistent effect on the power evaluation effect. Then we can get the normalization matrix $\boldsymbol{Z_k}$ of the *n*th indicators of the *k*th control layer subsystem where $\boldsymbol{Z_k}=[z_1, z_2,\ldots, z_n]$.

- The selection of the Fuzzy Membership function

The third step is to evaluate each indicator, the rating is excellent, good, medium and poor, and comment set can be expressed as $\boldsymbol{P}=\{p_1, p_2, p_3, p_4\}$. For the normalization matrix $\boldsymbol{Z_k}$, the Fuzzy demarcation interval of 4 state levels is given, and the membership function of each state level is established.

$$l_{p1}=\begin{cases}0 & z\le 0.6\\ 0.5+5(z-0.7) & 0.6<z\le 0.8\\ 1 & z>0.8\end{cases} \tag{1}$$

$$l_{p2}=\begin{cases}0 & z\le 0.4\\ 0.5+5(z-0.5) & 0.4<z\le 0.6\\ 0.5-5(z-0.7) & 0.6<z\le 0.8\\ 0 & z>0.8\end{cases} \tag{2}$$

$$l_{p3}=\begin{cases}0 & z\le 0.2\\ 0.5+5(z-0.3) & 0.2<z\le 0.4\\ 0.5-5(z-0.5) & 0.4<z\le 0.6\\ 0 & z>0.6\end{cases} \tag{3}$$

$$l_{p4}=\begin{cases}1 & z\le 0.2\\ 0.5+5(z-0.3) & 0.2<z\le 0.4\\ 1 & z>0.4\end{cases} \tag{4}$$

2.2.2 Combination Weighting

Because of the ambiguity of the assessment indicators, this paper uses fuzzy logarithmic method to weighting the indicators. The fuzzy judgment matrix $\tilde{A}$ is shown in formula (5), which represents the relative importance of the factor D_i comparison with factor D_j, l_{ij} and m_{ij} represent the lower and upper bounds of the triangular fuzzy $\tilde{a}_{ij}$, and u_{ij} represents the optimal value.

$$\tilde{A}=\left(\tilde{a}_{ij}\right)_{n\times n}=\begin{bmatrix}\tilde{a}_{11} & \tilde{a}_{12} & \cdots & \tilde{a}_{1n}\\ \tilde{a}_{21} & \tilde{a}_{22} & \cdots & \tilde{a}_{2n}\\ \vdots & \vdots & \cdots & \vdots\\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & \tilde{a}_{nn}\end{bmatrix}=\begin{bmatrix}(1,1,1) & (l_{12},m_{12},u_{12}) & \cdots & (l_{1n},m_{1n},u_{1n})\\ (l_{21},m_{21},u_{21}) & (1,1,1) & \cdots & (l_{2n},m_{2n},u_{2n})\\ \vdots & \vdots & \cdots & \vdots\\ (l_{n1},m_{n1},u_{n1}) & (l_{n2},m_{n2},u_{n2}) & \cdots & (1,1,1)\end{bmatrix} \tag{5}$$

Set w_i' as the weight of the indicator D_i, the logarithmic form of the fuzzy judgment matrix is as follows:

$$\mu_{ij}\left(\ln\left(\frac{w_i'}{w_j'}\right)\right)=\begin{cases}\dfrac{\ln\left(\dfrac{w_i'}{w_j'}\right)-\ln l_{ij}}{\ln m_{ij}-\ln l_{ij}} & \ln\left(\dfrac{w_i'}{w_j'}\right)\le m_{ij}\\[2ex] \dfrac{\ln u_{ij}-\ln\left(\dfrac{w_i'}{w_j'}\right)}{\ln u_{ij}-\ln m_{ij}} & \ln\left(\dfrac{w_i'}{w_j'}\right)> m_{ij}\end{cases} \tag{6}$$

where $\mu_{ij}\left(\ln\left(w_i'/w_j'\right)\right)$ represents the membership $\ln\left(w_i'/w_j'\right)$ of the fuzzy matrix $\ln\tilde{a}_{ij}$. Making φ the minimum membership, δ_{ij} and η_{ij} as non-negative error parameters, and M as the specified large values, the fuzzy logarithmic model can be expressed as:

$$\min J = \left(1-\varphi\right)^2 + M \times \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \left(\delta_{ij}^2 + \eta_{ij}^2\right)$$

$$s.t. \begin{cases} x_i - x_j - \varphi \ln\left(m_{ij} / l_{ij}\right) + \delta_{ij} \geq \ln l_{ij} \\ -x_i + x_j - \varphi \ln\left(u_{ij} / m_{ij}\right) + \eta_{ij} \geq -\ln u_{ij} \\ \lambda, x_i \geq 0 \\ \delta_{ij}, \eta_{ij} \geq 0 \end{cases} \tag{7}$$

where $x_i = \ln w_i'$. According to the inequality, we can find the optimization solution x_i^*, and then get the weight value of the fuzzy judgment matrix:

$$w_i' = \frac{\exp\left(x_i^*\right)}{\sum_{j=1}^{n}\left(x_i^*\right)} \tag{8}$$

Although fuzzy logarithmic method solves the problem of the complex system of energy and power supply, it still belongs to the subjective weighting method, so the anti-entropy method is added to amend the above method.

It should be noted that the anti-entropy method measures the comparison between the evaluation objects, focusing on the comprehensive evaluation of the seven kinds of power supply in the object layer. If z_{kj} is the standard value of indicator *i* under the *k*th evaluation object, the information output of indicator *i* is anti-entropy E_i is shown as:

$$E_i = -\sum_{k=1}^{7}\left(z_{ki}' \cdot \ln\left(1 - z_{ki}'\right)\right) \tag{9}$$

$$z_{ki}' = \frac{z_{ki}}{\sum_{k=1}^{7} z_{ki}} \tag{10}$$

The weight coefficients output by anti-entropy method is:

$$w_i'' = E_i / \sum_{j=1}^{n} E_j \tag{11}$$

In summary, the subjective weight w_i' is obtained by fuzzy logarithmic method, the objective weight matrix w_i'' is obtained by the anti-entropy method, and the important coefficients α_i and β_i of the main objective weights of each indicator are calculated according to the moment estimation theory, and the final calculation of the combined weights is shown below.

$$\begin{cases} \alpha_i = w_i' / \left(w_i' + w_i''\right) \\ \beta_i = w_i'' / \left(w_i' + w_i''\right) \end{cases} \tag{12}$$

$$w_i = \frac{\alpha_i w_i' + \beta_i w_i''}{\sum_{j=1}^{n}\left(\alpha_j w_j' + \beta_j w_j''\right)} \tag{13}$$

At this point, we can get the weight vector $\boldsymbol{W_k}$=[w_1, w_2,…, w_n] of *n*th indicators of the *k*th control layer subsystem.

2.2.3 Comprehensive Fuzzy Evaluation Model

According to the membership matrix $\boldsymbol{L_k}$ of the *n*th indicators of the *k*th control layer subsystem and the indicator weight vector $\boldsymbol{W_k}$, the membership degree matrix $\boldsymbol{G_k}$ of each subsystem of the control layer can be calculated by formula (14).

$$G_k = W_k L_k = \left[g_k\left(p_1\right) \quad g_k\left(p_2\right) \quad g_k\left(p_3\right) \quad g_k\left(p_4\right)\right] \tag{14}$$

For the *i*th power supply, the comprehensive evaluation membership matrix $\boldsymbol{H_i}$ can be calculated according to the five subsystems membership matrix $\boldsymbol{N_i}$=[$\boldsymbol{G_{i1}}$, $\boldsymbol{G_{i2}}$, $\boldsymbol{G_{i3}}$, $\boldsymbol{G_{i4}}$, $\boldsymbol{G_{i5}}$], and the control layer weight factor $\boldsymbol{W_i}$.

$$H_i = W_i L_i = \left[h_{i1} \quad h_{i2} \quad h_{i3} \quad h_{i4}\right] \tag{15}$$

where h_{ij} (*j*=1, 2, 3, 4) is the membership value corresponding to the *i*th power supply.

Set λ_i is the weight of various energy and power supplies in the energy structure (*i*=1, 2, 3, 4, 5, 6, 7). To maximize the combination of comprehensive scoring values as the goal function, adding resources, environment and policies and other constraints, maximize the regional power grid power combination of the comprehensive benefits, the target function is as follows:

$$\max J = \sum_{i=1}^{7} \sum_{j=1}^{4} \lambda_i \cdot q_j \cdot h_{ij} \tag{16}$$

where q_i is the score for membership, and q_1=90, q_2=70, q_3=50 and q_4=30. to q4 for 90, 70, 50 and 30, respectively. With a installed capacity of Si for the seven energy and power supplies in the regional grid, the optimization model needs to meet the following constraints:

- Power demand constraints

The sum of the various energy and power generation capacities of the regional grid must meet the maximum forecast of regional power demand:

$$\sum_{i=1}^{6} S_i \cdot T_i \geq \left(1+\gamma\right) D_{\max} \tag{17}$$

where T_i is the utilization hours of various power supplies, $D_{\max}$ is the maximum forecast of power demand, and $\gamma$is the system backup rate.

- Maximum installed capacity constraints

The installed capacity of renewable energy should be less than the maximum economically exploitable capacity $N_{i\_\max}$:

$$S_i \le N_{i\_\max} \tag{18}$$

- Environmental constraints

Environmental constraints mainly consider pollutants emitted from the atmosphere. The emissions of sulfur dioxide, nitrogen oxides, dust and carbon dioxide from the power supply shall be lower than the limit of pollutant emissions:

$$\sum_{i=1}^{6} S_i \cdot T_i \cdot \kappa_{i\_\mathrm{SO_2}} \le P_{\mathrm{SO_2}} \tag{19}$$

$$\sum_{i=1}^{6} S_i \cdot T_i \cdot \kappa_{i\_\mathrm{NO}_x} \le P_{\mathrm{NO}_x} \tag{20}$$

$$\sum_{i=1}^{6} S_i \cdot T_i \cdot \kappa_{i\_\mathrm{YC}} \le P_{\mathrm{YC}} \tag{21}$$

$$\sum_{i=1}^{6} S_i \cdot T_i \cdot \kappa_{i\_\mathrm{CO_2}} \le P_{\mathrm{CO_2}} \tag{22}$$

- Structure constraints

In addition, it is also necessary to consider that the various energy and power supply weights in the regional power grid should be between 0 and 1, and that the sum of the weights is equal to 1.

$$0 \le \lambda_i \le 1 \tag{23}$$

$$\sum_{i=1}^{6} \lambda_i = 1 \tag{24}$$

By solving the above-mentioned objective function, we can get the optimal solution of weight λ_i^* and installed capacity S_i^*, and then the optimal normalization score J^* of local power and energy for each area can also be obtained, and the difference between 1 and J^* will be the normalization score of competitiveness for energy and power interconnection in each area.

3 MODEL RESULTS

According to the concept of competitiveness for energy and power interconnection and the corresponding assessing model, the paper takes southeast Asian power grid as an example to analyse. Firstly, through authoritative energy agencies to investigate the largest economic development capacity, electricity costs and other quantitative indicators, and according to empirical experts to determine policy support and other qualitative indicators, the indicator assignment matrix ***B***, further the indicator normalization matrix ***Z*** is shown in Table 1.

Secondly, the fuzzy judgment matrix is determined, and the weight value of each indicator is obtained according to the fuzzy matrix. According to the influence degree of each subsystem, drawing on the authoritative research conclusions, the fuzzy judgment matrix is set as follows:

$$\tilde{A} = \begin{bmatrix} \tilde{1} & 1/\tilde{3} & 1/\tilde{3} & 1/\tilde{7} & 1/\tilde{9} \\ \tilde{3} & \tilde{1} & \tilde{1} & 1/\tilde{3} & 1/\tilde{5} \\ \tilde{3} & \tilde{1} & \tilde{1} & 1/\tilde{3} & 1/\tilde{5} \\ \tilde{7} & \tilde{3} & \tilde{3} & \tilde{1} & 1/\tilde{3} \\ \tilde{9} & \tilde{5} & \tilde{5} & \tilde{3} & \tilde{1} \end{bmatrix} \tag{25}$$

Similarly, the fuzzy judgment matrix of the indicator layer indicator can be obtained, and use the fuzzy-logarithmic and anti-entropy combination weighting method proposed in this paper to get the indicator weight matrix ***W***, as shown in Table 2.

Table 1: Indicator normalization matrix.

	Coal	Gas	Nuclear	Oil	Hydro	Wind	Solar
D1	0.09	0.11	0.16	0.06	0.80	0.90	1.00
D2	0.80	0.90	1.00	0.90	0.90	0.80	1.00
D3	0.69	0.74	1.00	0.86	0.69	0.63	0.60
D4	0.80	0.70	1.00	0.90	0.60	0.70	0.60
D5	0.80	1.00	1.00	0.90	0.67	0.60	0.60
D6	0.92	0.77	0.85	0.84	0.60	0.81	0.64
D7	0.60	1.00	1.00	0.60	1.00	1.00	1.00
D8	0.60	0.79	0.99	0.60	1.00	1.00	0.92
D9	0.60	0.98	1.00	0.60	1.00	1.00	1.00
D10	0.60	0.71	1.00	0.60	1.00	1.00	1.00
D11	0.60	1.00	1.00	0.45	1.00	1.00	1.00
D12	0.73	0.91	0.82	0.55	0.60	1.00	1.00

Table 2: Indicator weight matrix.

Subsystem	Indicator	Indicator weight			Subsystem weight
		fuzzy-logarithmic	anti-entropy	combination	
C1	**D1**	0.5547	0.4998	0.5271	0.31
	D2	0.4453	0.5002	0.4729	
C2	**D3**	0.5940	0.4525	0.5170	0.21
	D4	0.4060	0.5475	0.4830	
C3	**D5**	0.5066	0.5000	0.5033	0.21
	D6	0.4934	0.5000	0.4967	
C4	**D7**	0.2744	0.2135	0.2377	0.16
	D8	0.2744	0.2135	0.2377	
	D9	0.2744	0.2135	0.2377	
	D10	0.1768	0.3594	0.2870	
C5	**D11**	0.5488	0.4270	0.4754	0.11
	D12	0.4512	0.5729	0.5247	

According to the membership matrix L_k of the kth control layer subsystem nth indicators and the indicator weight vector W_k as determined in Table 2, the membership matrix G_k of the kth subsystem of the control layer is calculated. Then, according to the subsystem membership matrix and weight coefficient, the membership matrix H is calculated, which can be evaluated comprehensively by various power supplies, as shown in formula (26):

$$H = \begin{bmatrix} H_1 \\ H_2 \\ H_3 \\ H_4 \\ H_5 \\ H_6 \\ H_7 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0.636 & 0.364 \\ 0 & 0.546 & 0.454 & 0 \\ 0 & 0 & 0.775 & 0.225 \\ 0 & 0 & 0.374 & 0.626 \\ 0 & 0.794 & 0.206 & 0 \\ 0.813 & 0.187 & 0 & 0 \\ 0.631 & 0.361 & 0 & 0 \end{bmatrix} \quad (26)$$

The target function (16) is solved to obtain optimal normalization score for local energy and power structure in Southeast Asia, and finally the normalization score for competitiveness of energy and power interconnection in Southeast Asia can also be obtained. The results show that competitiveness of energy and power interconnection score between 0.6 and 0.8 from 2030 to 2060, which means energy and power interconnection has strong competitiveness in Southeast Asia compared with local energy and power.

We also use the proposed assessing model in areas along the Belt and Road, as shown in Fig.2. The results show that in the mid-term Southeast Asia is the main area for developing energy and power interconnection, and with the growth of population and economy, South Asia has quite strong demand for energy and power interconnection, where the competitiveness scores as high as 0.91. Other areas along the Belt and Road has less demand for energy and power interconnection due to the abundant local energy and slow-growing economy.

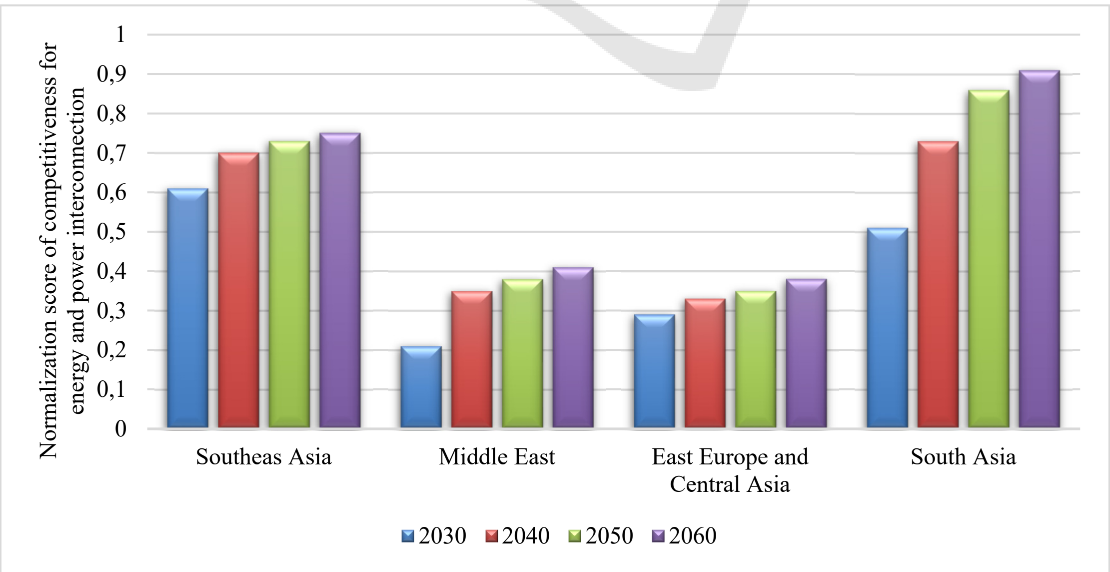

Figure 2: Normalization score of competitiveness for energy and power interconnection.

4 CONCLUSIONS

This paper sets up an evaluation system for the energy and power structure of regions along Belt and Road, into which resources, economy, technique, environment and policy are taken. What's more, this paper proposes an assessing model for the competitiveness model of the global energy and power interconnection, based on this model, it is possible to further carry out a comprehensive and scientific quantitative assessment of the regions along the Belt and Road, and provide a decision-making reference for the construction of power interconnection.

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