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# "Grouping" or "Ride One's Coattails"?—How Developing Countries along the Belt and Road Satisfy Themselves

**Jinghan Chen [1], Wen Zhou [2,*], Hongtao Yang [3] and Zhuofei Wu [4]**

[1] School of Economics and Management, Harbin Engineering University, Harbin 150001, China; chenjinghan@hrbeu.edu.cn
[2] College of System Engineering, National University of Defense Technology, Changsha 410073, China
[3] School of Business Administration, Huaqiao University, Quanzhou 362021, China; yht@hqu.edu.cn
[4] College of Computer Science and Technology, Harbin Engineering University, Harbin 150001, China; wzfhrb@hrbeu.edu.cn
* Correspondence: zhouwen@nudt.edu.cn

**Abstract:** China's Belt and Road Initiative (BRI) will inevitably affect global energy cooperation. Along the Belt and Road, there are many developing countries. To understand the energy cooperation and development of these countries comprehensively is of great significance to guide their development and evaluate the impact of the BRI on the world energy and economic pattern. However, there is insufficient attention on those countries. Based on embodied energy analysis, a method which can track direct and indirect energy consumption in the economic system, effectively linking energy with the economy and environment, this paper proposes an evolution model of the embodied energy flow of the countries. Then, it simulates the evolution of the embodied energy flow under different cooperation strategies. The results show that if cooperation between countries positively affects their cooperation with other countries, adopting a mixed strategy is an advisable choice. On the contrary, cooperation with "powerful" countries in the network will be more conducive to the embodied energy flow. This article provides a new perspective and foundation for further discussion on the economy, trade, and energy cooperation along the Belt and Road.

**Keywords:** embodied energy; embodied energy flow network; energy policy; energy cooperation; evolution simulation and modeling; the "Belt and Road Initiative"

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## 1. Introduction

Energy is essential for economic and social development and improved quality of life in all countries [1]. For most countries globally, energy security is one of the most important focuses of their national strategy. Due to the uncertainty and instability in the energy supply chain, such as the fragile and aging infrastructure, national energy security is increasingly threatened [2], especially for enormous energy-consuming countries like China. Therefore, it proposed the One Belt One Road Initiative (BRI), the world's most extensive infrastructure construction plan, and energy cooperation is an important component of it [3]. The BRI will contribute to constructing a more sustainable economic growth pattern, which may improve the overall energy efficiency of countries along the route [4]. In BRI, China is committed to expanding energy cooperation between countries, especially energy infrastructure construction and energy exploration and development. Some scholars believe that countries and regions along the route such as Russia, Mongolia, and Central Asia should seize the strategic opportunity of the BRI to strengthen cooperation with China [5–8]. In the meantime, some perspectives think these countries need to aware of the risks caused by the continuous growth of China's influence and policy unsustainability caused by some factors like geopolitical conflict [9–11]. However, most of the existing studies are based on direct energy cooperation, ignoring the flow and cooperation of indirect energy in the flow of a large number of products and services between countries along the Belt and Road. At the same time, there is insufficient attention to the underdeveloped areas along the Belt and Road. Along the Belt and Road, except for 16 high-income countries, including Singapore, Qatar, and the United Arab Emirates, most developing countries have a per capita GDP of less than 45% of the world average. At least half of the lower-middle and low-income countries have a per capita GDP of less than 2000 dollars, only 18.3% of the global average [12]. With the implementation of the BRI, the development of these underdeveloped regions will inevitably lead to an increase in resource consumption [13]. Extensively understanding the evolution of their energy consumption is essential to evaluate the BRI, understand real energy cooperation relations between countries, and further study environment issues and then guide their energy policy formulation and development strategy.

Simultaneously, the energy crisis and environmental issues have also made the global energy transition a general trend. However, the existing international energy security framework follows the traditional arrangement that focuses on ensuring the supply of oil for the United States and Europe. It is skeptical of newcomers and lacks institutional arrangements to effectively respond to the increase in oil demand in developing countries. At the same time, additional renewable energy production may slow the depletion of traditional energy reserves, reduce carbon dioxide ($CO_2$) emissions, and provide benefits to the environment [14], considering cooperation in renewable energy is also essential. Hence, establishing a new type of international energy cooperation could ensure a win-win situation between developed and developing countries. Its foundation is that all countries need to be integrated into an overall system, comprehensively considering the relationship between energy and the economy and energy and the environment [15]. However, the traditional evaluation based on direct energy is insufficient to capture all energy transfer among economies and may overestimate or underestimate the actual energy requirement of a country [16,17]. Therefore, embodied energy, a concept originated in system ecology, which is defined as the total (direct and indirect) energy required to produce economic or environmental goods and services [18,19], has been introduced to study energy-related issues. Embodied energy analysis can integrate historical and offsite formation and thus provide a more systematic perspective of energy use [20]. Moreover, because of its ability to track energy consumption in the economic system, it has become a hot topic in research related to determining the impact of the economy on the environment [21–27]. By using trade and input-output data between countries, calculating the embodied energy flow between countries can clarify the actual energy dependence between countries [16,19]. Moreover, it can introduce the complex interdependence between various countries and industrial sectors from a global perspective [28]. It reflects the number of resources that a country or a specific department can obtain from the upstream countries and relevant departments of the upstream countries in the global value chain, thus reflecting its development status from the energy perspective. The BRI may change the current pattern of international trade networks [29,30], and it will inevitably affect the energy flow pattern embodied in trade. For the underdeveloped and developing countries along the route, although they do not necessarily have direct energy import and export relations with other countries, there are energy cooperation relationships because of the flow of products and services. By observing the embodied energy flow relationship, on the one hand, we can understand the status of these countries in the Belt and Road energy cooperation network and lay a comprehensive and reliable foundation for discussing their development. On the other hand, with the help of network evolution in complex network analysis theory, it also provides an effective way to reasonably explore their development trend of energy consumption and further judge these regions' development direction based on this trend.

Therefore, this article aims to propose an embodied energy flow network between the Belt and Road countries and observe the development status of the underdeveloped and developing countries in the network from the perspective of embodied energy. Moreover, through embodied energy analysis, which can reflect the energy required and consumption-embodied trade between countries, we can clarify the current status of their actual energy cooperation relations with other countries by observing their energy flow relationships. Then, by referring to the evolutionary ideas of the BBV model in complex network analysis, we establish a model for the evolution of embodied energy flows between countries along the Belt and Road. Based on this model, we compare the changes in the embodied energy flow between these developing countries and other countries due to changes in cooperative relations under different cooperation strategies. The results may provide a reference for discussing the development strategies of developing countries from the energy perspective. They may also lay a good foundation for further research on energy and environmental sustainability in the future.

## 2. The Belt and Road Embodied Energy Flow Network

### 2.1. Embodied Energy and Its Calculation

Embodied energy is the total (direct and indirect) energy required for the production of economic or environmental goods and services [19]. Specifically, in the study of trade energy issues, embodied energy is the direct and indirect energy consumed by imported and exported goods and services in international trade. It is the production and transportation consumed when products and services are transferred from one region to another and the direct and indirect energy consumed by the entire link of the flow of products and services between industries or departments [16,31–35]. It has the characteristics of comprehensiveness, flowability, separability, and scalability [23]. Its most outstanding value is that it can effectively reflect the actual energy dependence between countries, connecting energy and economical energy with the environment [16,36,37]. From the perspective of energy consumption, through embodied energy, we can understand all the energy required for the operation of the economic system. It also provides an evaluable basis for studying environmental problems caused by energy consumption, such as the study of embodied emissions based on the extension of embodied energy.

The most widely used method for calculating implied energy is the multi-regional input-output model (MRIO), reflecting the energy consumption and flow relationships of various regions more accurately. The data for calculating the embodied energy in this article comes from the Eora 26 database. Eora 26 is a complete global MRIO table, plus environmental satellite account, in a harmonized 26-sector classification. It is a system that includes 189 economies, 26 sectors of each economy, and 6 final demand projects in the world. Figure 1 shows a typical MRIO model. In this model, the world economy is divided into m countries or regions, and each country and region contains n economic sectors or commodities. T is the intermediate usage matrix, representing the flow of goods from sector j in y area to sector i in x area, expressed in dollars. $F$ represents the final demand, which is divided into 6 columns. The primary input required by the output of sector i in area x is represented by $V$. In our data set, it is represented by $d$ and its measurement unit is $KJ$ [38]. Specifically, in MRIO, primary energy input includes natural gas, coal, petroleum, nuclear power, hydropower, geothermal power, wind power, solar, tidal and wave power, biomass energy, and waste power.

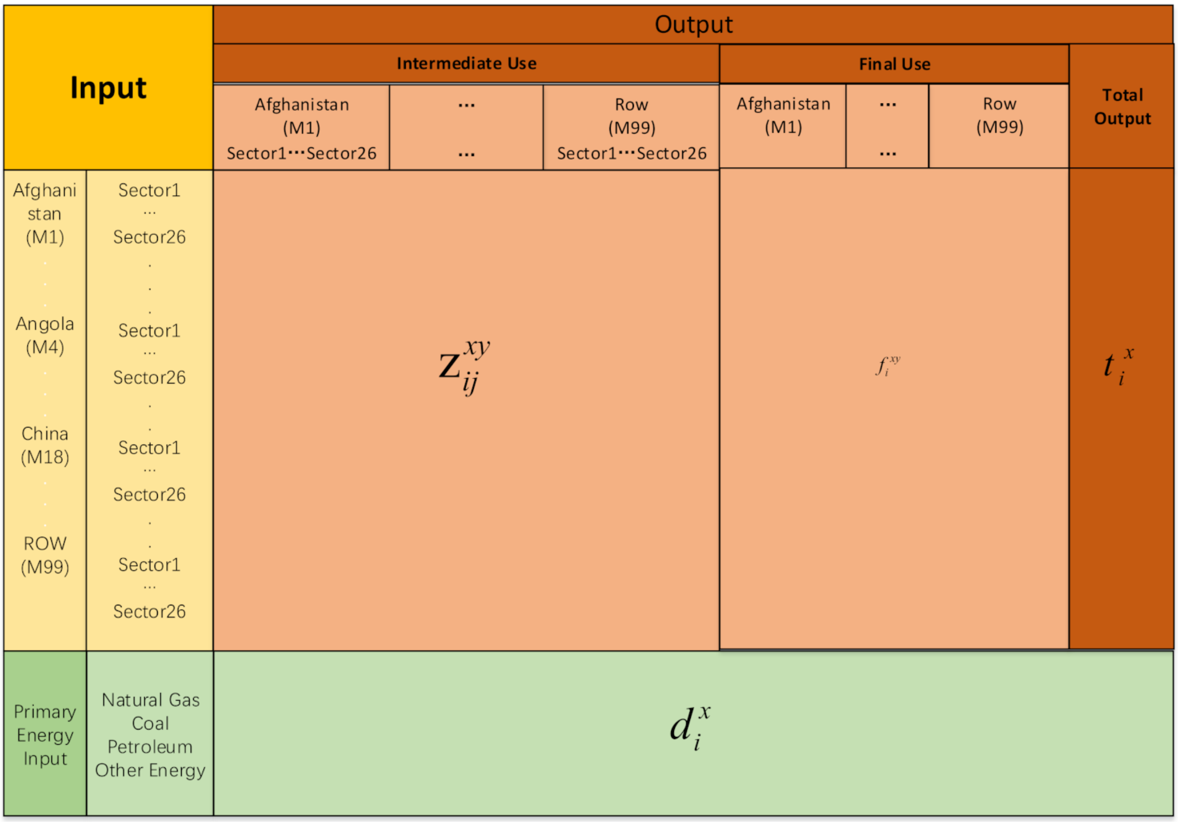



**Figure 1.** Sketch Map of a Revised MRIO table.

In the embodied energy flow model, the core principle is the balance of material energy. The total embodied energy input of a specific region or an industrial sector is equal to the total output of embodied energy. Figure 2 shows the balance of energy input and output of different industrial sectors in different regions, where $d$ denotes the direct energy use of sector i in area x, $\varepsilon$ represents the total energy intensity, and $Z$ represents the intermediate input of sector j in area y to sector i in area x. $F$ represents the final demand of sector i in area x. Therefore, the embodied energy balance relationship between sectors can be expressed as Formula (1).

$$\mathrm{d}_i^x + \sum_y \sum_j \left( \varepsilon_j^y + z_{ij}^{xy} \right) = \sum_y \sum_j \varepsilon_i^x \left( z_{ij}^{xy} + f_i^{xy} \right) \quad (1)$$

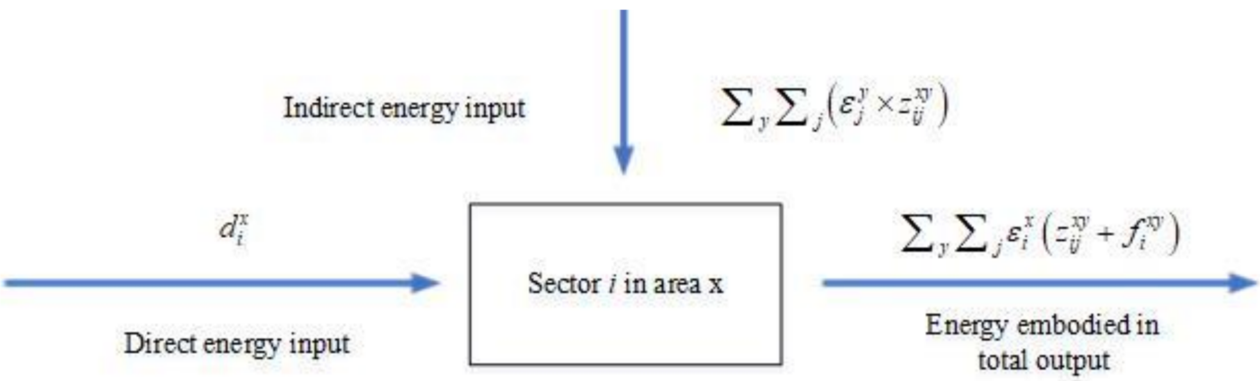



**Figure 2.** The principle of balance of embodied energy for sector *i* in the region.

In our research, we calculate the embodied energy by calculating the total energy intensity $\varepsilon$. The total energy intensity of an area represents the actual energy use (direct and indirect) produced by a certain sector in the area [18,39]:

$$\varepsilon = d\hat{t}^{-1} \tag{2}$$

where $d$ is a row vector, representing the energy use of each sector in one area. $\hat{t}^{-1}$ is an inverse matrix of diagonalized total output $t$.

Then, the domestic energy demand in the domestic production in area $x$ can be calculated using the following formula:

$$E^{xx} = \varepsilon^{x}(1 - A^{xx})^{-1} f^{xx} \tag{3}$$

The embodied energy flow between areas can be expressed as:

$$E^{xy} = \varepsilon^{x}(1 - A^{xx})^{-1} t^{xy} \tag{4}$$

Among them, $f^{xx}$ represents the final demand in x area. $t^{xy}$ represents the part of the intermediate and final demand in area $y$ that is produced by area $x$.

### *2.2. Network Construction and Network Characteristics*

In network analysis, the network is a system that contains a large number of individuals and the interactions between them. Then, the individuals are the nodes of a network, and the interactions and relationships of individual detection are the connections of the nodes in the network, which are represented by edges. In different networks, nodes and edges have different meanings. In this article, nodes represent countries, and edges represent the embodied energy flow relationship between countries, which is the energy cooperation relationship in the form of embodied energy. Then, with the advancement of network science and analysis technology, there are many indicators and algorithms to help us understand different complex networks, such as degree, degree distribution, degree centrality, strength, strength distribution, community detection, etc. In a network, node degree represents the number of its neighbors and how many edges are connected to it. It is usually used to measure the importance of the node. The strength represents the interaction between nodes. The strength distribution represents the probability that the strength is a special value [40]. In this article, the degree indicates how many countries have energy cooperation relations with one country. The strength represents the degree of energy cooperation between the two countries, expressed as the amount of embodied energy flow. There are two indicators of it, edge strength and node strength, where the edge strength is specific to the numerical value, it is the amount of embodied energy flow between the two countries, and the node strength is the sum of the strength of all edges connected to a node.

#### 2.2.1. Network Construction and Its Characteristic

To evaluate the status and role of countries along the Belt and Road in the network, this article focuses on countries that have signed the Belt and Road bilateral agreements or cooperation memos. Then, based the available data in the Euro database, this paper finally compiled the input-output data of 99 countries in 2011, 2013, and 2015 (the list of these 99 countries is in Table A1 in Appendix A). Through the MRIO model, we calculated the embodied energy flow between these countries and built the embodied energy flow network along the Belt and Road through R and Gephi software. Furthermore, with the network feature analysis, the relationship model between the Belt and Road countries is examined, which can provide data support for the next evolution model proposal. In this network, there are 99 nodes, representing 99 countries along the Belt and Road, and if there is embodied energy import and export between two countries, there is an edge. For example, if China imports energy from Russia, in the network there is an edge from

Russia to China. Thus, the edges between nodes are directed edges, representing the flow direction and quantity of embodied energy among countries.

Benefiting from the development of globalization, the embodied energy flow network between countries along the Belt and Road is a fully connected network, which means that there are embodied energy flow relationships between each country and other countries along the Belt and Road; there are no isolated nodes in the network. The network density is always 1.

As shown in Figure 3, to better show the evolution of the BRI countries' energy cooperation relationship, we only retain the edges with the weight in the top 90%. It can be seen from Figure 3 that the number of connected edges has not changed significantly in the three years, and only a few countries have a large amount of embodied flows, like China, Russia, and Korea.

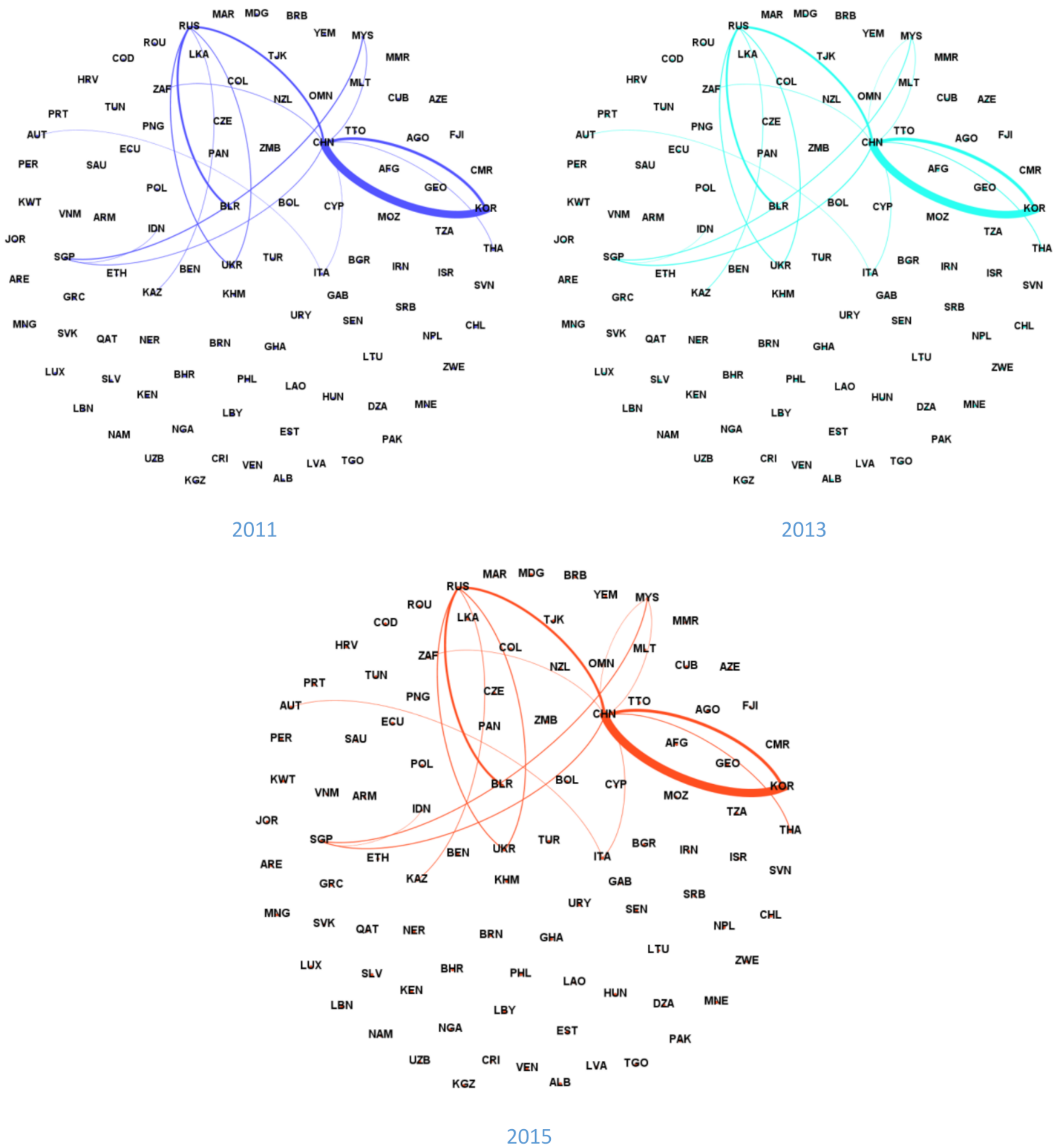



**Figure 3.** Embodied energy flow network of the Belt and Road.

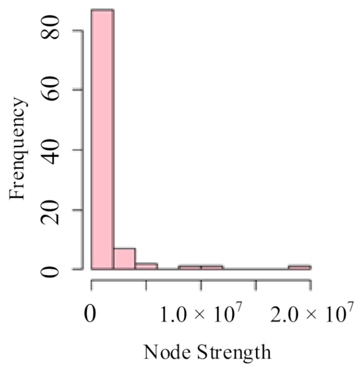
Table 1 shows the countries' total embodied energy flow strength along the Belt and Road, the amount of embodied energy flow of the top 20 countries, and the amount of energy outflow and inflow. Because the amount of embodied energy flows between most countries is very small, from Figure 3 we can see that when we remove the edges with a weight less than 10% of the maximum weight, the number of edges plummeted. Only a few countries, such as South Korea and China and China and Russia, have a significant amount of embodied energy flow. Table 1 also confirms that countries such as China, South Korea, Russia, Jamaica, Singapore, South Africa, Maldives, Iraq, Iran, and Ukraine have appeared in the top 20 countries. It can be seen that the total intensity or embodied energy flow in 2015, 2013, and 2011 are 108017767,6, 112773348,5, and 95953890, 11, respectively. However, the distribution of overall strength is not even. The top three countries are China, South Korea, and Russia, and their total strength accounts for nearly 50% of the total network strength. In 2011, 2013, and 2015, China's embodied energy flow accounted for 19%, 20.8%, and 20.3% of the entire network. South Korea accounted for 11.3% in 2011 and 11.6% in 2013 and 2015. Russia accounted for 10.3%, 10.6%, and 10.7%. Then, the strength of the top 20 countries accounted for nearly 90% of the total strength. Specifically, the energy flows of the remaining 79 countries only account for 16.3%, 16.8%, and 16% of the total energy flows. This means that those countries' total embodied energy flow is not as much as that of China.

**Table 1.** Total strength and the top 20 countries with embodied energy flows strength in countries along the Belt and Road.

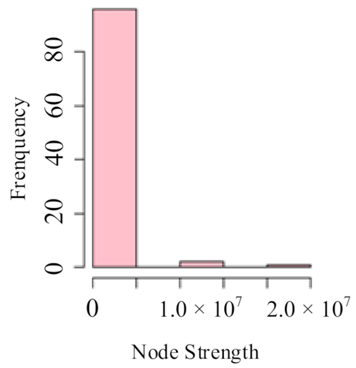
| | 2015 | | | | 2013 | | | | 2011 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Network Total Strength** | **108.02** | | | | **112.77** | | | | **95.95** | | |
| | **Total Strength** | **Out Strength** | **In Strength** | | **Total Strength** | **Out Strength** | **In Strength** | | **Total Strength** | **Out Strength** | **In Strength** |
| CHN | 21.93 | 10.14 | 11.79 | CHN | 23.49 | 11.05 | 12.43 | CHN | 18.28 | 7.74 | 10.53 |
| KOR | 12.51 | 7.65 | 4.86 | KOR | 13.11 | 7.86 | 5.25 | KOR | 10.83 | 6.4 | 4.44 |
| RUS | 11.64 | 7.39 | 4.25 | RUS | 11.99 | 7.64 | 4.35 | RUS | 9.85 | 6.07 | 3.78 |
| ITA | 4.72 | 1.28 | 3.43 | ITA | 4.9 | 1.38 | 3.52 | ITA | 4.49 | 1.24 | 3.26 |
| SGP | 4.41 | 0.77 | 3.64 | SGP | 4.6 | 0.8 | 3.8 | SGP | 4.08 | 0.72 | 3.36 |
| MYS | 3.89 | 2.28 | 1.62 | MYS | 4.09 | 2.42 | 1.68 | ZAF | 3.84 | 3.2 | 0.64 |
| ZAF | 3.76 | 3.1 | 0.66 | ZAF | 3.95 | 3.26 | 0.69 | MYS | 3.76 | 2.39 | 1.37 |
| IRN | 3.12 | 2.18 | 0.94 | IRN | 3.25 | 2.28 | 0.97 | IRN | 3.29 | 2.54 | 0.75 |
| THA | 2.94 | 1.14 | 1.8 | THA | 3.11 | 1.23 | 1.87 | IDN | 2.79 | 1.68 | 1.11 |
| UKR | 2.93 | 1.61 | 1.32 | UKR | 3.04 | 1.69 | 1.35 | UKR | 2.74 | 1.61 | 1.13 |
| IDN | 2.84 | 1.6 | 1.24 | IDN | 3.01 | 1.69 | 1.32 | THA | 2.43 | 0.94 | 1.49 |
| AUT | 2.66 | 1.96 | 0.7 | AUT | 2.71 | 1.99 | 0.72 | AUT | 2.24 | 1.61 | 0.63 |
| TUR | 2.06 | 0.26 | 1.8 | TUR | 2.12 | 0.27 | 1.85 | TUR | 1.85 | 0.27 | 1.59 |
| BLR | 2.02 | 2 | 0.02 | SAU | 2.05 | 1.14 | 0.91 | BLR | 1.77 | 1.75 | 0.02 |
| SAU | 2 | 1.13 | 0.88 | BLR | 2 | 1.97 | 0.03 | SAU | 1.75 | 1.04 | 0.71 |
| KAZ | 1.82 | 0.94 | 0.88 | KAZ | 1.91 | 0.98 | 0.93 | KAZ | 1.63 | 0.87 | 0.76 |
| POL | 1.63 | 0.39 | 1.24 | POL | 1.68 | 0.41 | 1.27 | POL | 1.41 | 0.35 | 1.06 |
| ARE | 1.52 | 0.69 | 0.83 | ARE | 1.56 | 0.69 | 0.87 | ARE | 1.27 | 0.54 | 0.73 |
| CZE | 1.27 | 0.29 | 0.98 | CZE | 1.28 | 0.29 | 0.99 | CZE | 1.11 | 0.28 | 0.83 |
| ROU | 1.1 | 0.46 | 0.64 | PHL | 1.05 | 0.37 | 0.69 | PHL | 0.92 | 0.33 | 0.59 |

Unit:1 million Tj.

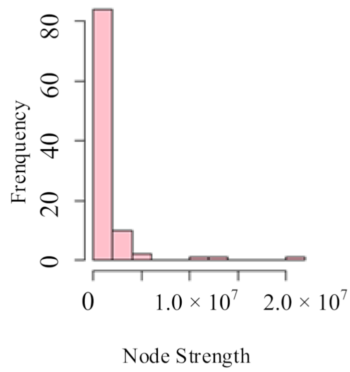
Figure 4 shows the distribution of embodied energy flow strength for each of the three years. It can be seen that the embodied energy flow of most countries is relatively low, and only a few countries are relatively high. However, in 2013 and 2015, especially in 2015, some countries' embodied energy strength increased, which confirms the results presented in Figure 4. The embodied energy flow strength of 97% of the BRI countries dramatically increased from 2011 to 2013, and then it fell slightly in 2015.




(**a**)Strength Distribution in 2011



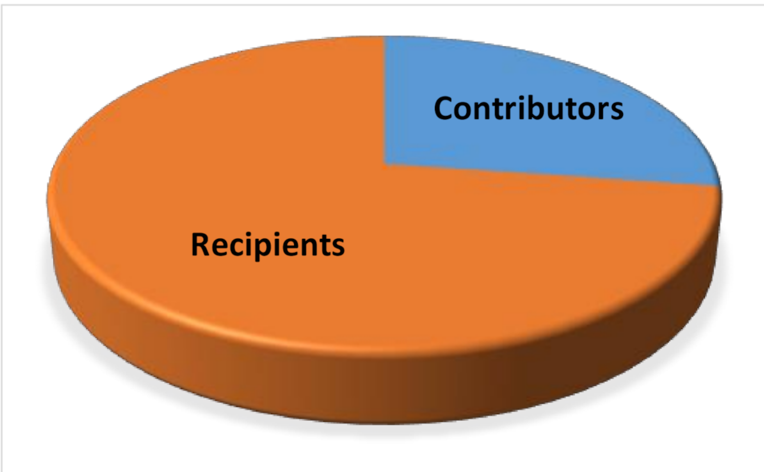

(**b**)Strength Distribution in 2013




(**c**)Strength Distribution in 2015

**Figure 4.** The embodied energy flow strength distribution.

Furthermore, Figure 5 shows the net embodied energy outflows and net inflows of countries along the Belt and Road in three years. Net inflow countries refer to countries with embodied energy outflows less than inflows. The number of countries with net inflows and with net outflows in the three years has not changed. Among the 99 countries along the Belt and Road, 27 are net exporters of embodied energy, and the remainder, including China, are net importers. In twelve countries, such as Malaysia, Afghanistan, and Gabon, the amount of embodied energy inflow accounts for more than 90% of their total embodied energy flow, which means that these countries have a high degree of embodied energy dependence.

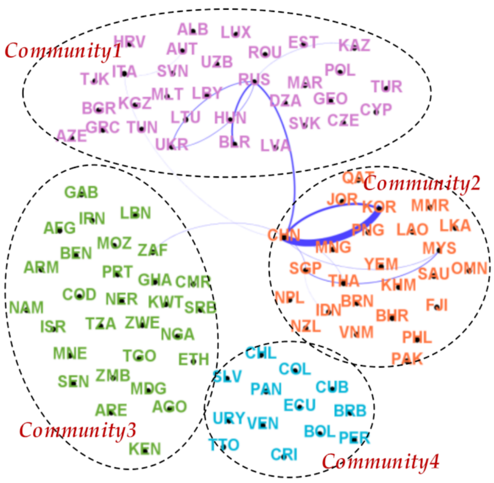



**Recipients:** China, Jamaica, Singapore, Thailand, Turkey, Poland, UAE, Djibouti, Romania, Philippines, Viet Nam, Indonesia, Slovakia, Guinea, Italy, Chile, Luxembourg, Kyrgyzstan, Costa Rica, New Zealand, Nigeria, Slovenia, Angola, Venezuela, Namibia, Peru, Kuwait, Portugal, Zambia, Ethiopia, Zimbabwe, Cuba, Azerbaijan, Laos, Lebanon, Morocco, Egypt, El Salvador, Kazakhstan, Tunisia, Ghana, Tanzania, Tajikistan, Lesotho, Serbia, Mozambique, Cyprus, Greece, Sri Lanka, Panama, Uruguay, Cambodia, Armenia, Czech Republic, Croatia, Nepal, Afghanistan, Trinidad and Tobago, Mauritania, Malaysia, Albania, Estonia, Cameroon, Senegal, Montenegro, Benin, Gambia, Latvia, Papua, New Guinea, Niger, Gabon, Barbados.
**Contributors:** South Korea, Russia, Maldives, South Africa, Iraq, Ukraine, Iran, Austria, Belarus, Saudi, Arabia, Kenya, Oman, Uzbekistan, Fiji, Bulgaria, Pakistan, Algeria, Qatar, Lithuania, Mongolia, Bahrain, Yemen, Brunei, Bolivia, Madagascar, Myanmar, Togo.

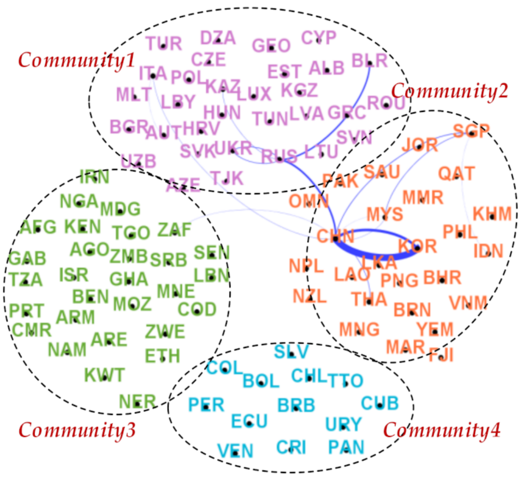
**Figure 5.** Recipients and contributors in the network.

#### 2.2.2. Community Detection

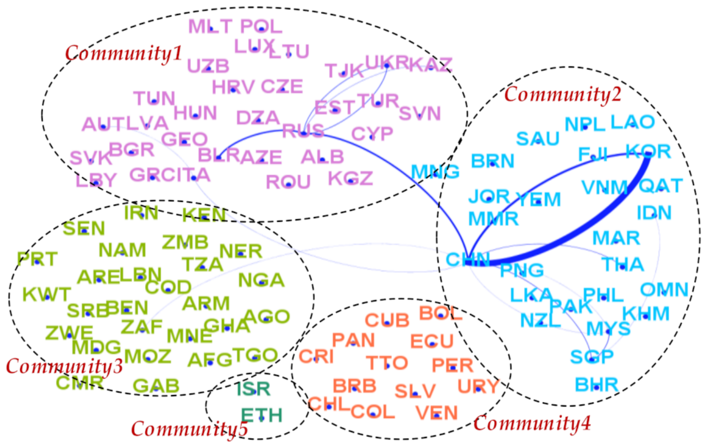
Furthermore, to analyze the characteristics and pattern of energy cooperation relations between countries along the Belt and Road, this paper also explores the community structure of the implied energy flow network of the Belt and Road Initiative. Figure 6 and Table 2 respectively show the test results of associations in the Belt and Road countries. In 2011 and 2013, there were no significant changes in the associations. The 99 countries along the Belt and Road were divided into four associations. In 2011, the first community was Russia-led, and its scale is the largest, covering 32 countries. This is followed by the community headed by South Africa and includes 29 countries. The third community is headed by China and South Korea, including 25 countries, and the last community includes 13 countries. It is worth noting that although the community headed by China and South Korea only contain about a quarter of the countries, their strength accounts for more than half of the total strength. Moreover, from Table 2, we can see that most members of each community belong to the same regional economic organizations, which means there is a closer energy cooperation relationship within these regional economic organizations.




(**a**) Community structure in 2011




(**b**) Community structure in 2013




(**c**) Community structure in 2015

**Figure 6.** Community structure of the network.

**Table 2.** Members of communities and related political and economic union of them.

| | Members | | | |
|---|---|---|---|---|
| | **2015** | **2013** | **2011** | **Related Political and Economic Union** |
| **Community 1** | ALB, DZA, AUT, AZE, BLR, BGR, HRV, CYP, CZE, EST, GEO, GRC, HUN, ITA, KAZ, KGZ, LVA, LBY, LTU, LUX, MLT, POL, ROU, RUS, SVK, SVN, TJK, TUN, TUR, UKR, UZB | AFG, AGO, ARM, BEN, CMR, COD, GAB, GHA, IRN, KEN, KWT, LBN, MDG, MNE, MOZ, NAM, NER, NGA, PRT, SEN, SRB, ZAF, TZA, TGO, ARE, ZMB, ZWE | ALB, DZA, AUT, AZE, BLR, BGR, HRV, CYP, CZE, EST, GEO, GRC, HUN, ITA, KAZ, KGZ, LVA, LBY, LTU, LUX, MLT, MAR, ROU, RUS, SVK, SVN, TJK, TUN, TUR, UKR, UZB | Arican Continental Free Trade Area (AfCFTA), European Union (EU) |
| **Community 2** | BHR, BRN, KHM, CHN, FJI, IDN, JOR, LAO, MYS, MNG, MAR, MMR, NPL, NZL, OMN, PAK, PNG, PHL, QAT, SAU, SGP, KOR, LKA, THA, VNM, YEM | BHR, BRN, KHM, CHN, FJI, IDN, JOR, LAO, MYS, MNG, MAR, MMR, NPL, NZL, OMN, PAK, PNG, PHL, QAT, SAU, SGP, KOR, LKA, THA, VNM, YEM | BHR, BRN, KHM, CHN, FJI, IDN, JOR, LAO, MYS, MNG, MMR, NPL, NZL, OMN, PAK, PNG, PHL, POL, QAT, SAU, SGP, KOR, LKA, THA, VNM, YEM | South Pacific Regional Trade Economic Cooperation Agreement (SPARTECA), Asia-Pacific Economic Cooperation (APEC) |
| **Community 3** | BRB, BOL, CHL, COL, CRI, CUB, ECU, SLV, PAN, PER, TTO, URY, VEN | BRB, BOL, CHL, COL, CRI, CUB, ECU, SLV, PAN, PER, TTO, URY, VEN | BRB, BOL, CHL, COL, CRI, CUB, ECU, SLV, PAN, PER, TTO, URY, VEN | Central American Common Market (CACM), La Comunidad Andina, Caribbean Community and Common Market (CARICOM) |
| **Community 4** | AFG, AGO, ARM, BEN, CMR, COD, GAB, GHA, IRN, KEN, KWT, LBN, MDG, MNE, MOZ, NAM, NER, NGA, PRT, SEN, SRB, ZAF, TZA, TGO, ARE, ZMB, ZWE | AFG, AGO, ARM, BEN, CMR, COD, GAB, GHA, IRN, KEN, KWT, LBN, MDG, MNE, MOZ, NAM, NER, NGA, PRT, SEN, SRB, ZAF, TZA, TGO, ARE, ZMB, ZWE | AFG, AGO, ARM, BEN, CMR, COD, ETH, GAB, GHA, IRN, ISR, KEN, KWT, LBN, MDG, MNE, MOZ, NAM, NER, NGA, PRT, SEN, SRB, ZAF, TZA, TGO, ARE, ZMB, ZWE | AfCFTA |

In summary, from the perspective of embodied energy, all developing regions along the Belt and Road have energy cooperation relations with other countries in the network. However, these relationships are in a weak position due to their national strength or natural resources endowment. To enhance the status of these countries in the network, they need to find suitable strategies to strengthen cooperation with other countries and enhance their influence in the network.

## 3. Analysis of Strategies for Increasing the Amount of Embodied Energy Flows of Developing Countries Based on the BBV Model

Based on the above analysis of the embodied energy flow network of the Belt and Road, we can see that a large number of developing countries are in a "marginal" and weak position in the network. Moreover, the network is already a fully connected network, which means nodes in the network cannot increase their degree by generating new connections to enhance their status in the network. Therefore, to improve these countries' status, from the perspective of network evolution, they need to find a suitable strategy to increase their strength, which represents the amount of embodied energy flow between themselves and other countries.

The BBV model is an evolution model proposed by Barret, Bathelemy, and Vespignani, different from the unweighted network. In this model, weights and topology evolve and influence each other at the same time. At the same time, if a new connection edge appears after a new node joins in the network, the weight brought by the new edge will also cause the weight of the existing edge in the network to change [41–43]. For example, during the implementation of the BRI, new countries continue to join, and the joining of new countries will inevitably lead to changes in the overall network. Similarly, the cooperation relationship between existing countries in the network will also change continuously, such as because of the BRI, many countries have more opportunities for cooperation with China. Furthermore, these changes would also affect other countries in the network.

### *3.1. Evolution Model Based on BBV Model and Real Network Data*

The cooperation network between the Belt and Road countries is a dynamic and complex network system. Each country constitutes a node of this complex network, and this network continues to grow and evolve. The evolution process is a complex and dynamic process, including the participation of new countries and the evolution of cooperative relations between countries. Unlike some other networks like social networks, the countries along the Belt and Road are relatively fixed. Its unlimited evolution is more reflected in the relationship between nodes (countries) and nodes (countries) themselves rather than the increase or decrease of nodes (countries). The evolution for the number of nodes has boundaries. In the evolution of edges, in the real world, the previous cooperation between countries is affected by many factors, such as geographic location, resource endowment, politics, and religion. Therefore, to reflect the network structure of cooperation between the Belt and Road countries and ensure that the research results have corresponding practice, we propose the Belt and Road energy cooperation evolution model based on the actual embodied energy flow network data. It has the following characteristics:

1. The number of nodes is fixed: Since this article mainly considers the influence of the continuous strengthening of cooperation between the existing One Belt One Road countries and the preferred choice of partners of selected countries, the evolution of this article is more based on the actual network data to investigate the evolution of node strengths and edge weights.
2. Heterogeneity between nodes: Due to the differences in economic development and resource endowments between the Belt and Road countries, there are huge differences between the Belt and Road countries, and these heterogeneities will also affect their tendency to cooperate in the network and the benefits of cooperation. Since the model in this article is based on an embodied energy flow network, a network based on real input and output data, considering it from the perspective of embodied flow, nodes with greater strength are also more critical in the network, like China.

Therefore, the Belt and Road embodied energy cooperation network proposed in this article initially has 99 nodes. They represent 99 countries along the Belt and Road. According to the actual embodied flow network data in 2011, the initial point weights are respectively assigned, and the network is fully connected. The weight of each edge is equal to their amount of embodied energy flow, and directionality is not considered. The initial point weight is equal to the sum of all edge weights connected to it.

Simultaneously, according to the comparative advantage theory [44,45] and related research on geopolitics, cooperation between countries is usually based on differences in resource endowments, and geographical proximity has also become an essential basis for national cooperation [46–48], like various regional economic groups. Moreover, due to the uneven development of the world economy, some developing countries lack the bargaining chip to compete with developed countries. They are usually at the lower level of participants in the global supply chain, such as raw material production, primary processing, and labor-intensive industries. In order to further improve their power of discourse in international affairs, they tend to form alliances. However, it is undeniable that it is also the best or only choice for many developing countries to become a host country of eliminated industries from developed countries or their supplier of primary products in a period. Therefore, the design of cooperative evolution of developing countries in this paper is based on two strategies. One is "grouping," that is, they prefer to cooperate with other developing countries. The other is "ride one's coattails" (ROC), which means they prefer to cooperate with other developed countries. Then, according to different strategic tendencies, there are different evolution mechanisms.

*3.2. Evolution Mechanism*

*V* represents countries along the Belt and Road in the embodied energy cooperation network G (*V*, *E*) of the Belt and Road, and *V* = 99. *E* is the edge set, and it represents the relationships because of embodied energy flow between these countries. The initial value of E is the amount of embodied energy flow between each country in 2011, and according to the strength distribution, this article mainly considers those countries where their node strength accounts for less than 10% of the total network strength. Then, countries are chosen that want to enhance cooperation according to different preference strategies. Formula (5) shows the process of selecting the initial node of the evolution model.

$$V_i \in V, \left( \frac{S_{V_i}}{\sum_1^{99} S_V} < 0.1 \right) \tag{5}$$

$S_{V_\mathrm{i}}$ is the node strength of $V_\mathrm{i}$,which equals the sum of the edge weights of all its connected edges. In this paper, it denotes the total amount of embodied energy flow between country *i* and other countries.

3.2.1. Evolution Process under the Group Strategy

1. Selection of partners
   Under the group strategy, the developing countries tend to cooperate with the same type of countries to gain power of discourse in cooperation with other countries. Therefore, in each evolution time step, nodes are more likely to cooperate with nodes with the same or even smaller strength. The priority probability that partner *j* would be chosen is as follows:

$$\prod(j \to i) = \frac{\sum_{j=1}^{99} S_j - S_i}{\sum_{j=1}^{99} S_j} \tag{6}$$

2. Increase the weight of edges
   When in time step *t*, node chooses to cooperate with *j*, which is also a node with small node strength. The strengthening of cooperation will inevitably lead to increased trade exchanges and cooperation between the two countries, leading to an increase in the amount of embodied energy flow, supposing the growth is $\Delta w_{ij}$. In addition, the increase of edge strength will affect the cooperation with their "neighbors"; that is to say, the edge weight between the node and its neighbors will also be affected. Suppose that the change is $\gamma$. When the selected nodes strengthen their cooperation, the new edge weight $w_{ij_t}$ is:

$$w_{ij_t} = w_{ij_{t-1}} + \Delta w_{ij} + \gamma \tag{7}$$

   Many factors would affect the growth of embodied energy flows due to the strengthening of cooperation, for example, the country's resource endowment, areas of co-operation between two countries, and geographical distance. However, no matter how it changes, it will not digress from their original basis of cooperation. In order to simplify the calculation, in the evolution model:

$$\Delta w_{ij} = \varepsilon * w_{ij_{t-1}} \tag{8}$$

   $\varepsilon$ is the growth coefficient, based on the real node strength data in 2011, 2013, and 2015, the growth rate is mostly between 0 and 0.6, so this paper sets it to be a random number between 0 and 0.6 in simulation experiments and a specific value is chosen in the final simulation in the same range.

$$\gamma = \theta * \Delta w_{ij} \tag{9}$$

$\theta$ is the extension effect coefficient, which represents the extent of the impact on the edge weight between selected nodes and their neighbors. To simplify the calculation, the value of $\theta$ is between $-1$ and 1 because the extension effect could positively influence other neighbors and also may be negative for other nodes.

3. The edge weight change between grouping nodes and their neighbors (excluding members of the group):
Because of the extension effect, it will be affected by the original cooperative relationship.

$$w_{ix_t} = \frac{w_{ix_{t-1}}}{S_i} * \gamma + w_{ix_{t-1}} \tag{10}$$

$$w_{jy_t} = \frac{w_{jy_{t-1}}}{S_j} * \gamma + w_{jy_{t-1}} \tag{11}$$

Formula (10) represents the node strength change between the initially selected node and its neighbor nodes except the selected nodes in the group in a time step. Formula (11) represents the edge weight change between the selected nodes and their neighbor nodes outside the group. Based on BBV's idea of preference for edge weights, this paper argues that the extension effect will also be affected by the original cooperative relationship, that is, a closer previous relationship would be affected more significantly.

#### 3.2.2. Evolution Process under the Strategy of "Ride One's Coattails"

Compared with the "grouping" strategy, the only difference of "ride one's coattails" is that when the initial node is selecting partners to strengthen cooperation, it is preferred to strengthen cooperation with superior nodes in the network. Therefore, the difference in the evolution process is mainly reflected in the choice of partners. The other evolution steps and mechanisms are the same.

1. Selection of partners
Under the "ride one's coattails" strategy, selection preference is the same as the traditional BBV model. The country with a more considerable node strength is easier to be selected. We assume that each time step selects one crucial node in the network to strengthen cooperation. Formula (8) shows the priority probability:

$$\prod(j \to i) = \frac{S_j}{\sum_{j=1}^{99} S_j} \tag{12}$$

2. Increase the weight of edges
Similar to the "grouping" strategy, when a partner is selected, the edge weight between them and their neighbors would change. The calculation formula is shown in Formulas (7)–(11).

#### 3.2.3. Evolution Process under the Strategy of "Random Mixed"

In the real world, the choice of national cooperation strategies is often more complicated. It is not simply chosen to "group" or "ride one's coattails" but is more a combination of the two strategies, just as the reality of the embodied energy flow network is a fully connected network. However, specific to each decision, it can still be attributed to cooperating with countries of similar development levels ("grouping"), cooperating with key countries in the network (ROC), or both. Therefore, to better compare whether a single strategy or a mixed strategy, such as in the real world, has different effects on national development, we design a random group to simulate reality. Specifically, after selecting the initial node, a random mixed strategy is used to select several cooperation target nodes within a single time step that is to be strengthened. The other evolution steps and mechanisms are the same.

Under the randomly mixed strategy, the node has no particular preference, so we use the following steps to achieve the node selection:

1. Randomly choose a ratio $\phi$ and $\phi \in (0, 1)$
2. Randomly choose $n$ counties as partners

$$n = 99 * \phi \tag{13}$$

The subsequent changes in the edges' strength are the same as the previous two strategies.

### *3.3. Analysis of Empirical Results*

In order to better compare the evolution and development of small weight nodes in the cooperation network of countries along the Belt and Road under different strategies, this paper designs two sets of evolutionary experiments. First, we compared the evolution of the node strength of the initial randomly selected nodes under different strategies. Then, we compared the point weight evolution state of a specific node under different strategies. In addition, to further analyze the possible application scenarios of the two strategies and explore better strategies in a specific context. This article adjusts the parameters and observes the experimental results under different parameters to achieve deeper insights.

#### 3.3.1. Simulation Experiment Based on Random Selection of Initial Nodes

In the experiment, we mainly adopted five sets of data simulations and compared their results. In group 1, $\varepsilon$ is 0.3 and $\theta$ is 0.2; in group 2, $\varepsilon$ is 0.1 and $\theta$ is $-0.1$; in group 3, $\varepsilon$ is 0.1 and $\theta$ is 0.2; in group 4, $\varepsilon$ is 0.3 and $\theta$ is 0.5; in group 5, $\varepsilon$ is 0.6 and $\theta$ is 0.2. Figure 6 presents the nodes' strength distribution of the simulation experiments when the time step is 20. In order to ensure that the evolution model we proposed can better simulate reality, before the simulation, we added a comparison and fitting experiment with the realistic embodied energy flow network in 2015 to ensure that our simulation experiment has practical reference significance. Figure 7 shows the node strength distribution under different parameters and strategies, and Figure 8 shows the results of the fitting experiment.

We can see that the nodes' strength distributions are approximately subject to the power rate distribution. This evolutionary result is consistent with the nodes' strength distribution of the existing network in 2013 and 2015 (Figure 4), verifying the correctness of our model in this article. At the same time, to further make the simulation results match the actual network, we compared the node strength results of each strategy under different parameters with the existing network in 2015 and carried out a K-S test. Figure 7 compares the cumulative distribution curve of simulated data (time step equal to 30) and actual data in the KS test.

From Figure 7, we can see how the model simulation results fit the actual data. Except when the parameters are 0.3 and 0.5 under the "grouping" strategy, the simulation results do not match reality, but all other $p$ values are greater than 0.85. That means that our simulation results and actual network data conform to the same distribution. Looking further at the D value, when the time step is 30 times, the difference between the two sets of data is also tiny, proving the effectiveness of our model.

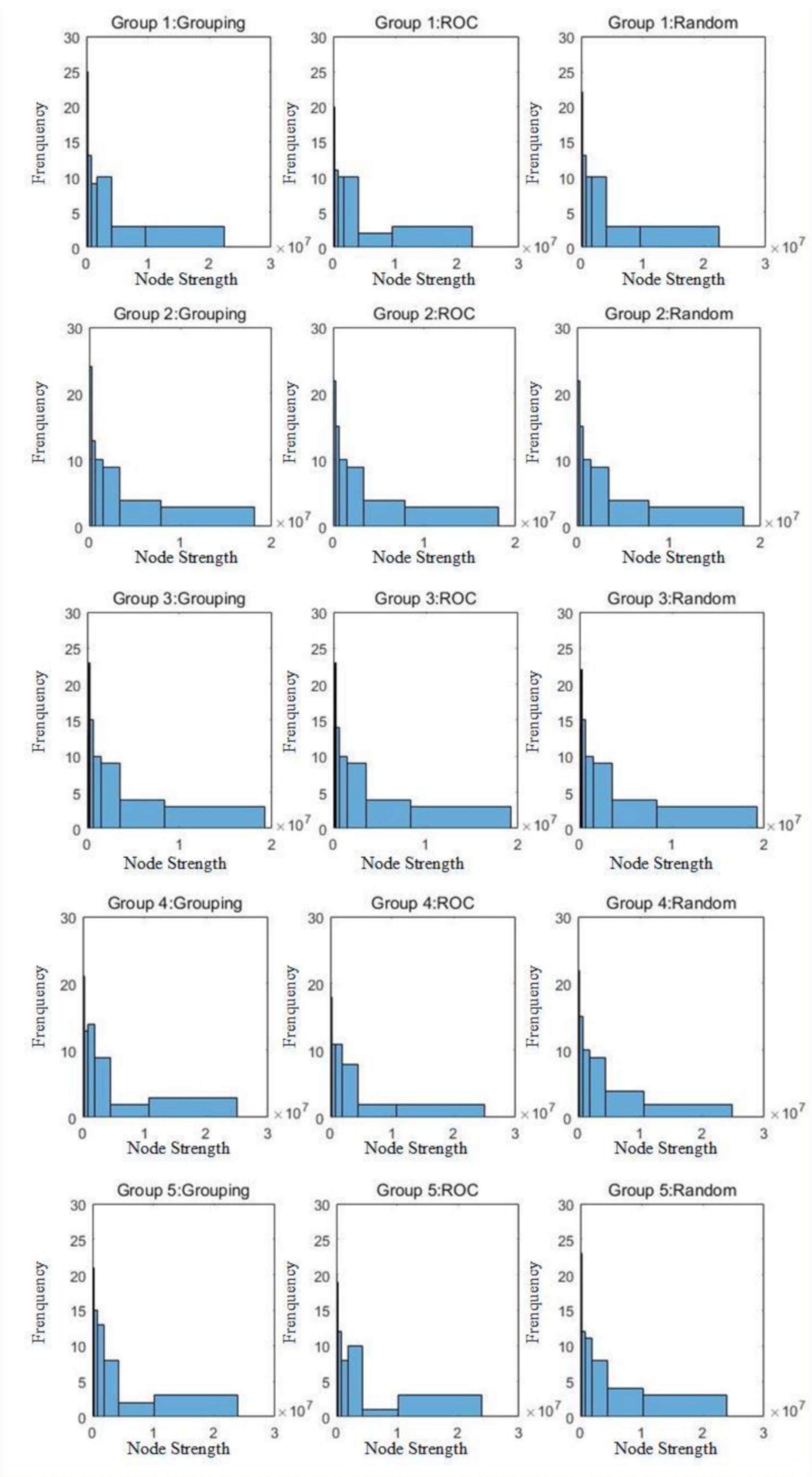
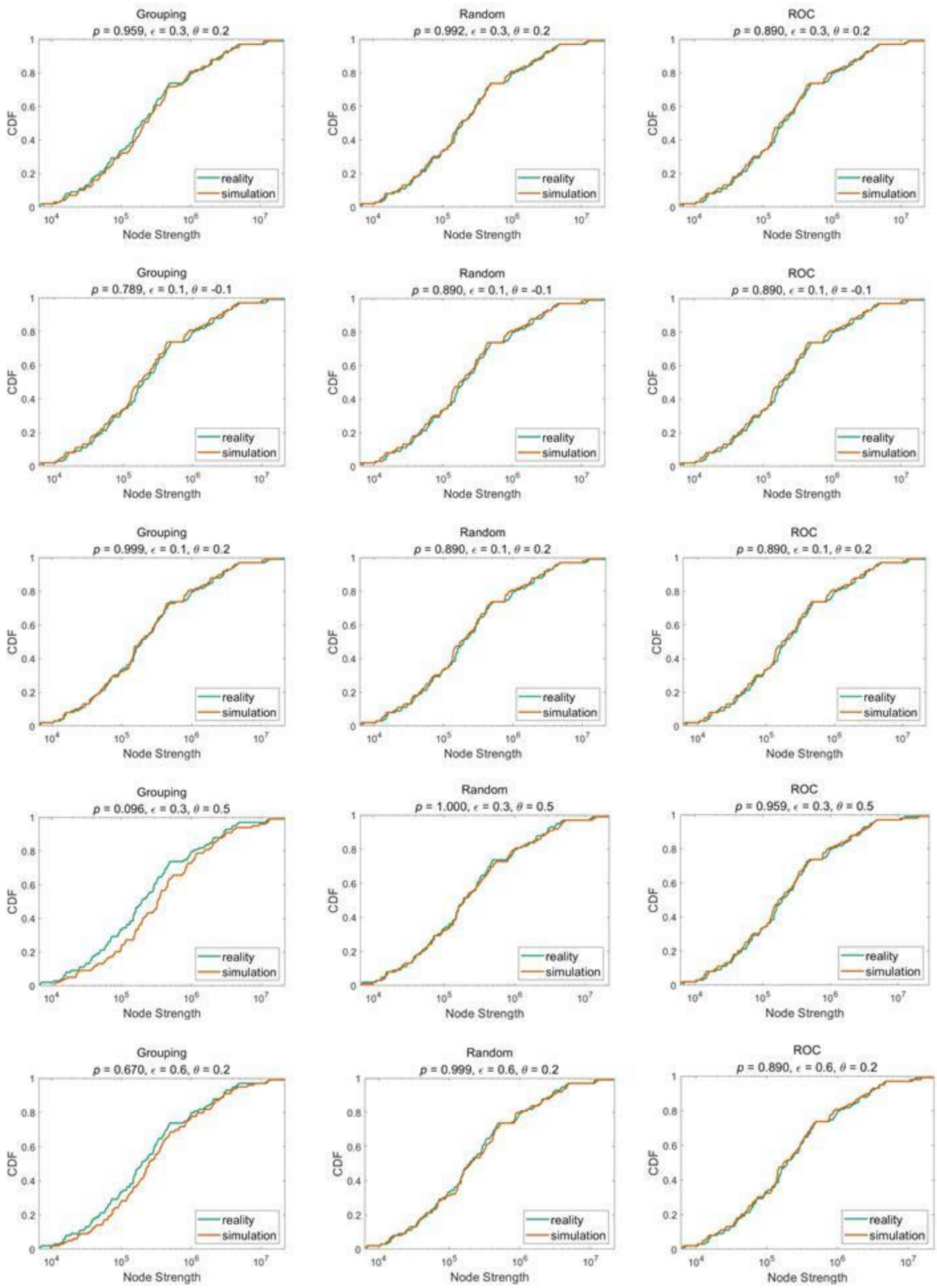



**Figure 7.** Node strength distribution.




Time steps = 30, CDF: Cumulative distribution frequency

**Figure 8.** Cumulative distribution curve of simulated data and actual data in K-S test.

In this paper, the simulation results under the third set of parameters with the ideal fitting results are selected to compare the simulation results. That is, the growth coefficient is 0.1, and the extension influence parameter is 0.2. In those parameters, when the time step is 10, 89% of the node strength under the "grouping" strategy is bigger than their node strength under the "ride one's coattail" strategy. When the time step is 20, the ratio increased to 93%, and 95% when the time step is 30. Therefore, compared with the "ride one's coattail" strategy, "grouping" generally has better results for those developing countries, although this advantage is not apparent in absolute terms. It means that for those developing countries in the Belt and Road, seeking to construct cooperation alliances with countries similar to their development levels positively influences their development. However, what is interesting is that the performance of a single strategy and the results of the mixed strategy adopted in the simulated reality are different in the short term and mid-to-long term. In the short term, when the time step is 10, "grouping" is still a relatively optimal strategy; 56.6% of the node strength is greater than the results under the "random mixed" strategy test. However, when the step size is greater than or equal to 20, the "random mixed" strategy gradually shows its advantages. About 52 to 64% of the node strength is greater than the results under the "grouping" strategy. In a word, regardless of a short-term or long-term perspective, "ride one's coattails" seems to be the last choice for developing countries along the Belt and Road to enhance their influence in the network.

### 3.3.2. Simulation Experiment Based on the Specified Initial Node

In order to further verify the development status of developing countries under different strategies, in this paper, we specify the initial nodes based on random experiments and randomly select three countries for the specified experiments, but the other parameters of the designated node experiment and the random experiment are the same. These three countries are the Angola (AGO), The Republic of Lithuania (LTU), and Senegal (SEN). Figure 9 compares the node strength evolution results of three countries under different time steps and strategies.

As shown in Figure 8, under the "grouping" strategy, the relative speed and absolute amount of node strength growth of these four countries are better than those under the "ride one's coattail" strategy. The results further prove the superiority of the group strategy over the direct "ride one's coattail" strategy.

In addition, it is worth noting that although the "grouping" strategy is more conducive to the development of small nodes than the "ride one's coattail" strategy, it will affect the development of large nodes, that is, the developed countries in the network. From the simulation results, the node strength development of 90% of the nodes under the "grouping" strategy is better than the "ride one's coattail" strategy.

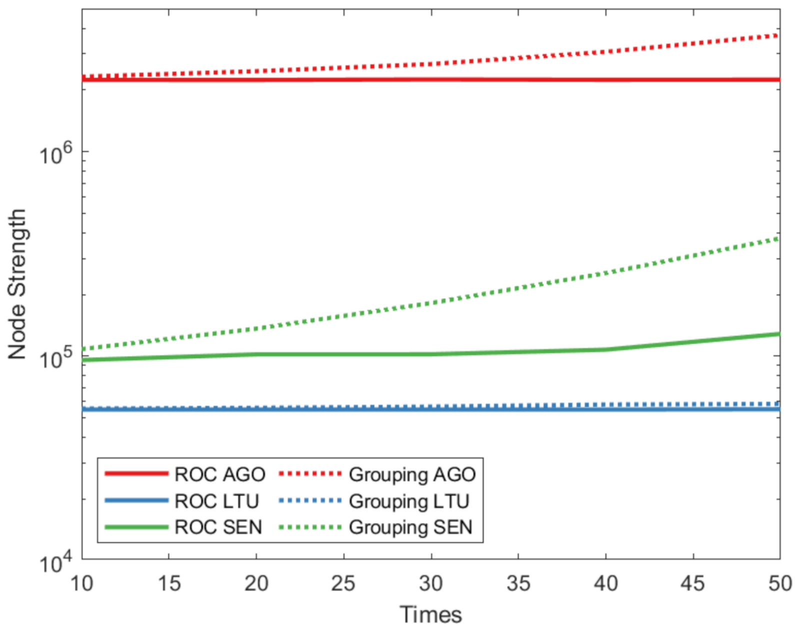



**Figure 9.** Node strength evolution results.

#### 3.3.3. Parameter Sensitivity Analysis

The comparative test conducted in this article mainly involves the growth parameters and the extension influence parameters. In order to verify the effective boundary of the superiority of the strategy, we have done many experiments, and the simulation results prove that the growth parameters do not affect the comparative advantage of the strategy. It will only affect the amount of the embodied energy flow under the two strategies. The comparative relationship between the advantages of the two strategies has not been changed. However, when the extended influence parameter is negative, strategic comparative advantages have been reversed. The "ride one's coattail" strategy is more conducive than the "grouping" strategy. Table 3 shows the ratio of the node strength in different parameters under the "grouping" and "random mixed" strategy over the node strength under "ride one's coattail" (the time step is 30). It can be seen that when the extended influence parameter is a positive value, more than 90% of the node strengths under the "grouping" and "random mixed" strategy are better than the result of another strategy. However, when the extended influence parameter becomes −0.1, this ratio drops to 10% and 28%, respectively.

**Table 3.** The proportion of node strength under "grouping" greater than under "ride one's coattail" and "random mixed".

| The Group of Parameters | Proportion Value (Grouping > ROC) | Proportion Value (Random > ROC) |
|---|---|---|
| group 1: $\varepsilon = 0.3$, $\theta = 0.2$ | 91% | 99% |
| group 2: $\varepsilon = 0.1$, $\theta = -0.1$ | 10% | 28% |
| group 3: $\varepsilon = 0.1$, $\theta = 0.2$ | 95% | 97% |
| group 4: $\varepsilon = 0.3$, $\theta = 0.5$ | 94% | 100% |
| group 5: $\varepsilon = 0.6$, $\theta = 0.2$ | 90% | 98% |

Time steps = 30.

As mentioned in the introduction to the simulation experiment, the extended influence coefficient represents that when a country chooses to strengthen cooperation with another country, it will inevitably affect its other neighbors. This effect may be the tilt of resource allocation (recover the resources initially allocated to other neighbors and allocate them to countries that plan to strengthen cooperation). It may also be a new opportunity (enhanced cooperation has led to the need for countries to import more external resources to achieve better results of cooperation). For example, suppose it is energy cooperation between the two countries. In that case, a country is ready to export more energy to a country that will strengthen cooperation. If it does not increase the mining volume, this would inevitably lead to a reduction in energy obtained by other countries. Moreover, if it is a production or a cooperative construction project, that may require purchasing much more raw materials from neighbors. Therefore, through the sensitivity analysis, we found that if enhancing cooperation between underdeveloped countries is based on resource transfer from other existing cooperation, it is better to cooperate with essential nodes in the network, which will be more conducive to their development.

## 4. Conclusions

This paper proposes a model for the evolution of embodied energy flows in countries along the Belt and Road based on the actual network of embodied energy flows data in the Belt and Road. Then, based on this, the impact of different strategies adopted by developing countries on their development is observed. The results show that: (1) The simulation model under different strategies can simulate the actual development path and fit the accurate network. It has practical significance. (2) For developing countries, in the long term, the "mixed random" strategy has a more positive influence on their development than the other two strategies, which is also in line with the reality that countries always adopt both strategies at the same time, and "ride one's coattail" seems the last choice for their development. (3) In contrast, if developing countries cannot allocate enough resources to support the strengthening of cooperation and need to transfer resources from other partners to support new cooperation, the "ride one's coattail" strategy will be the optimal choice. Hence, developing countries along the Belt and Road need to comprehensively consider the demand and content of foreign cooperation projects and their resource endowments. Supposing they do not have sufficient resources to support more new foreign cooperation, they can consider focusing resources on cooperation projects in countries similar to their development status.

The research conclusions of this article provide a valuable reference for the development path of the countries along the Belt and Road and provide a more comprehensive perspective to examine the development of these countries. It can reference future studies on these developing countries' energy consumption demand and sustainable development. However, it should be noted that we need to be cautious about the conclusions of this article because embodied energy represents all the energy contained in goods and services in the international cooperation network. The increase in a country's embodied energy flow may, on the one hand, represent the strengthening of its cooperation with other countries and its better development, and its importance in the entire network will be increased. However, at the same time, it is also necessary to consider the new problems like dependence state change caused by the increase in embodied energy flow. On the other hand, it also represents an increase in its energy consumption. If the energy input is non-renewable resources, it may hurt the global environment.

In the future, some limitations can be addressed in further research. For example, we can further consider the influence of more restrictive conditions such as geographical factors and project factors on the development of countries along the Belt and Road to make it play a more decisive practical guiding significance. Energy flow direction can be integrated into future research to address energy dependence related issues. Moreover, research can be extended to the industry level.

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**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix A

**Table A1.** Nations mentioned in this article.

| No. | Nations | Abbr. | No. | Nations | Abbr. | No. | Nations | Abbr. |
|---|---|---|---|---|---|---|---|---|
| 1 | Afghanistan | AFG | 34 | Guinea | GRC | 67 | Papua New Guinea | PNG |
| 2 | Albania | ALB | 35 | Indonesia | HUN | 68 | Peru | PER |
| 3 | Algeria | DZA | 36 | Iran | IDN | 69 | Philippines | PHL |
| 4 | Angola | AGO | 37 | Iraq | IRN | 70 | Poland | POL |
| 5 | Armenia | ARM | 38 | Italy | ISR | 71 | Portugal | PRT |
| 6 | Austria | AUT | 39 | Jamaica | ITA | 72 | Qatar | QAT |
| 7 | Azerbaijan | AZE | 40 | Kazakhstan | JOR | 73 | Romania | ROU |
| 8 | Bahrain | BHR | 41 | Kenya | KAZ | 74 | Russia | RUS |
| 9 | Barbados | BRB | 42 | Kuwait | KEN | 75 | Saudi Arabia | SAU |
| 10 | Belarus | BLR | 43 | Kyrgyzstan | KWT | 76 | Senegal | SEN |
| 11 | Benin | BEN | 44 | Laos | KGZ | 77 | Serbia | SRB |
| 12 | Bolivia | BOL | 45 | Latvia | LAO | 78 | Singapore | SGP |
| 13 | Brunei | BRN | 46 | Lebanon | LVA | 79 | Slovakia | SVK |
| 14 | Bulgaria | BGR | 47 | Lesotho | LBN | 80 | Slovenia | SVN |
| 15 | Cambodia | KHM | 48 | Lithuania | LBY | 81 | South Africa | ZAF |
| 16 | Cameroon | CMR | 49 | Luxembourg | LTU | 82 | South Korea | KOR |
| 17 | Chile | CHL | 50 | Madagascar | LUX | 83 | Sri Lanka | LKA |
| 18 | China | CHN | 51 | Malaysia | MDG | 84 | Tajikistan | TJK |
| 19 | Costa Rica | COL | 52 | Maldives | MYS | 85 | Tanzania | TZA |
| 20 | Croatia | CRI | 53 | Mauritania | MLT | 86 | Thailand | THA |
| 21 | Cuba | HRV | 54 | Mongolia | MNG | 87 | Togo | TGO |
| 22 | Cyprus | CUB | 55 | Montenegro | MNE | 88 | Trinidad and Tobago | TTO |
| 23 | Czech Republic | CYP | 56 | Morocco | MAR | 89 | Tunisia | TUN |
| 24 | Djibouti | CZE | 57 | Mozambique | MOZ | 90 | Turkey | TUR |
| 25 | Egypt | COD | 58 | Myanmar | MMR | 91 | UAE | ARE |
| 26 | El Salvador | ECU | 59 | Namibia | NAM | 92 | Ukraine | UKR |
| 27 | Estonia | SLV | 60 | Nepal | NPL | 93 | Uruguay | URY |
| 28 | Ethiopia | EST | 61 | New Zealand | NZL | 94 | Uzbekistan | UZB |
| 29 | Fiji | ETH | 62 | Niger | NER | 95 | Venezuela | VEN |
| 30 | Gabon | FJI | 63 | Nigeria | NGA | 96 | Viet Nam | VNM |
| 31 | Gambia | GAB | 64 | Oman | OMN | 97 | Yemen | YEM |
| 32 | Ghana | GEO | 65 | Pakistan | PAK | 98 | Zambia | ZMB |
| 33 | Greece | GHA | 66 | Panama | PAN | 99 | Zimbabwe | ZWE |

## References


1. Wei, S.; Yanfeng, X. Research on China's energy supply and demand using an improved Grey-Markov chain model based on wavelet transform. *Energy* **2017**, *118*, 969–984. [CrossRef]
2. Farrell, A.E.; Zerriffi, H.; Dowlatabadi, H. Energy infrastructure and security. *Annu. Rev. Environ. Resour.* **2004**, *29*, 421–469. [CrossRef]
3. Zhao, Y.; Liu, X.; Wang, S.; Ge, Y. Energy relations between China and the countries along the Belt and Road: An analysis of the distribution of energy resources and interdependence relationships. *Renew. Sustain. Energy Rev.* **2019**, *107*, 133–144. [CrossRef]
4. Qi, S.; Peng, H.; Zhang, X.; Tan, X. Is energy efficiency of Belt and Road Initiative countries catching up or falling behind? Evidence from a panel quantile regression approach. *Appl. Energy* **2019**, *253*, 253. [CrossRef]
5. Sun, G.; Yuan, C.; Hafeez, M.; Raza, S.; Jie, L.; Liu, X. Does regional energy consumption disparities assist to control environmental degradation in OBOR: An entropy approach. *Environ. Sci. Pollut. Res.* **2019**, *27*, 7105–7119. [CrossRef]
6. Hobér, K. Arbitration of Energy Disputes Under the Energy Charter Treaty: Added Value for the Belt and Road Initiative. *J. World Invest. Trade* **2019**, *20*, 285–312. [CrossRef]
7. Piao Guang-ji, L.F. "The Belt and Road" and China-Mongolia-Russia Energy Cooperation in A Perspective of Regional Security. *Asia-Pac. Econ. Rev.* **2016**, *7*, 3–9.
8. Kembayev†, Z. The Emerging Eurasian Common Energy Market: What is Its Potential Impact on China's Belt and Road Initiative? *J. World Invest. Trade* **2019**, *20*, 401–424. [CrossRef]
9. Zhang, Y. The Research on the Relationship of Economic and Trade among China and Countries along "The Belt And Road" under the Perspective of Conflicts. *Southwestern University of Finance and Economics*. 2017. Available online: https://www.zhangqiaokeyan.com/academic-degree-domestic_mphd_thesis/020315168211.html (accessed on 25 March 2021).

10. Haiquan, L. The Security Challenges of the "One Belt, One Road" Initiative and China's Choices. *Croat. Int. Relations Rev.* **2017**, *23*, 129–147. [CrossRef]
11. Shah, A.R. Revisiting China Threat: The US' Securitization of the 'Belt and Road Initiative'. *Chin. Politi-Sci. Rev.* **2021**. [CrossRef]
12. Wu, S. Economic Development of Countries along the "One Belt One Road". *Rev. Econ. Res.* **2017**, *28*, 16–25.
13. Sun, H.; Clottey, S.A.; Geng, Y.; Fang, K.; Amissah, J.C.K. Trade Openness and Carbon Emissions: Evidence from Belt and Road Countries. *Sustainability* **2019**, *11*, 2682. [CrossRef]
14. Zhang, W.; Yang, J.; Sheng, P.; Li, X.; Wang, X. Potential cooperation in renewable energy between China and the United States of America. *Energy Policy* **2014**, *75*, 403–409. [CrossRef]
15. Liu, Y.; Hao, Y. The dynamic links between CO2 emissions, energy consumption and economic development in the countries along "the Belt and Road". *Sci. Total Environ.* **2018**, *645*, 674–683. [CrossRef]
16. Chen, B.; Li, J.; Wu, X.; Han, M.; Zeng, L.; Li, Z.; Chen, G. Global energy flows embodied in international trade: A combination of environmentally extended input–output analysis and complex network analysis. *Appl. Energy* **2018**, *210*, 98–107. [CrossRef]
17. Kanemoto, K.; Lenzen, M.; Peters, G.P.; Moran, D.D.; Geschke, A. Frameworks for Comparing Emissions Associated with Production, Consumption, And International Trade. *Environ. Sci. Technol.* **2011**, *46*, 172–179. [CrossRef]
18. Lam, K.L.; Kenway, S.; Lane, J.L.; Islam, K.N.; de Berc, R.B. Energy intensity and embodied energy flow in Australia: An input-output analysis. *J. Clean. Prod.* **2019**, *226*, 357–368. [CrossRef]
19. Costanza, R. Embodied Energy and Economic Valuation. *Science* **1980**, *210*, 1219–1224. [CrossRef]
20. Chen, Z.-M.; Chen, G. Demand-driven energy requirement of world economy 2007: A multi-region input–output network simulation. *Commun. Nonlinear Sci. Numer. Simul.* **2013**, *18*, 1757–1774. [CrossRef]
21. Jiang, M.; An, H.; Guan, Q.; Sun, X. Global embodied mineral flow between industrial sectors: A network perspective. *Resour. Policy* **2018**, *58*, 192–201. [CrossRef]
22. Wang, X.; Yao, M.; Li, J.; Ge, J.; Wei, W.; Wu, B.; Zhang, M. Global embodied rare earths flows and the outflow paths of China's embodied rare earths: Combining multi-regional input-output analysis with the complex network approach. *J. Clean. Prod.* **2019**, *216*, 435–445. [CrossRef]
23. Chen, J.; Zhou, W.; Yang, H. Is Embodied Energy a Better Starting Point for Solving Energy Security Issues?—Based on an Overview of Embodied Energy-Related Research. *Sustainability* **2019**, *11*, 4260. [CrossRef]
24. Gasim, A. The embodied energy in trade: What role does specialization play? *Energy Policy* **2015**, *86*, 186–197. [CrossRef]
25. Wood, R.; Stadler, K.; Simas, M.; Bulavskaya, T.; Giljum, S.; Lutter, S.; Tukker, A. Growth in Environmental Footprints and Environmental Impacts Embodied in Trade: Resource Efficiency Indicators from EXIOBASE3. *J. Ind. Ecol.* **2018**, *22*, 553–564. [CrossRef]
26. Hao, H.; Liu, Z.; Zhao, F.; Geng, Y.; Sarkis, J. Material flow analysis of lithium in China. *Resour. Policy* **2017**, *51*, 100–106. [CrossRef]
27. Hashemi, A.; Cruickshank, H.; Cheshmehzangi, A. Environmental Impacts and Embodied Energy of Construction Methods and Materials in Low-Income Tropical Housing. *Sustainability* **2015**, *7*, 7866–7883. [CrossRef]
28. Feng, Z.; Zhou, W.; Ming, Q. Embodied Energy Flow Patterns of the Internal and External Industries of Manufacturing in China. *Sustainability* **2019**, *11*, 438. [CrossRef]
29. Cui, L.; Song, M. Economic evaluation of the Belt and Road Initiative from an unimpeded trade perspective. *Int. J. Logist. Res. Appl.* **2019**, *22*, 25–46. [CrossRef]
30. Wu, T.; Zhang, B.; Cao, Y.; Sun, P. Impact of Multi-Dimensional and Dynamic Distance on China's Exports of Wooden Forest Products to Countries along the "Belt and Road". *Sustainability* **2020**, *12*, 3339. [CrossRef]
31. Liu, H.; Xi, Y.; Guo, J.; Li, X. Energy embodied in the international trade of China: An energy input–output analysis. *Energy Policy* **2010**, *38*, 3957–3964. [CrossRef]
32. Sun, C.; Ma, T.; Xu, M. Exploring the prospects of cooperation in the manufacturing industries between India and China: A perspective of embodied energy in India-China trade. *Energy Policy* **2018**, *113*, 643–650. [CrossRef]
33. Xu, S.-C.; Gao, C.; Miao, Y.-M.; Shen, W.-X.; Long, R.-Y.; Chen, H.; Zhao, B.; Wang, S.-X. Calculation and decomposition of China's embodied air pollutants in Sino-US trade. *J. Clean. Prod.* **2019**, *209*, 978–994. [CrossRef]
34. Zhang, B.; Chen, Z.; Xia, X.; Xu, X.; Chen, Y. The impact of domestic trade on China's regional energy uses: A multi-regional input–output modeling. *Energy Policy* **2013**, *63*, 1169–1181. [CrossRef]
35. Shi, J.; Li, H.; Guan, J.; Sun, X.; Guan, Q.; Liu, X. Evolutionary features of global embodied energy flow between sectors: A complex network approach. *Energy* **2017**, *140*, 395–405. [CrossRef]
36. Cortés-Borda, D.; Guillén-Gosálbez, G.; Jiménez, L. Solar energy embodied in international trade of goods and services: A multi-regional input–output approach. *Energy* **2015**, *82*, 578–588. [CrossRef]
37. Wiedmann, T.; Lenzen, M.; Turner, K.; Barrett, J. Examining the global environmental impact of regional consumption activities — Part 2: Review of input–output models for the assessment of environmental impacts embodied in trade. *Ecol. Econ.* **2007**, *61*, 15–26. [CrossRef]
38. Lenzen, M.; Kanemoto, K.; Moran, D.; Geschke, A. Mapping the Structure of the World Economy. *Environ. Sci. Technol.* **2012**, *46*, 8374–8381. [CrossRef]
39. Wiedmann, T. On the decomposition of total impact multipliers in a supply and use framework. *J. Econ. Struct.* **2017**, *6*, 1109. [CrossRef]
40. Shize Guo, Z.L. *Basic Theory of Complex Networks*; Science Press: Beijing, China, 2012.

41. Barrat, A.; Barthélemy, M.; Vespignani, A. Weighted Evolving Networks: Coupling Topology and Weight Dynamics. *Phys. Rev. Lett.* **2004**, *92*, 228701. [CrossRef]
42. Topirceanu, A.; Udrescu, M.; Marculescu, R. Weighted Betweenness Preferential Attachment: A New Mechanism Explaining Social Network Formation and Evolution. *Sci. Rep.* **2018**, *8*, 10871. [CrossRef]
43. Zhang, X. A weighted network model based on node fitness dynamic evolution. In Proceedings of the 2016 IEEE 22nd International Conference on Parallel and Distributed Systems, Wuhan, China, 13–16 December 2016. [CrossRef]
44. Ricardo, D. *On the Principles of Political Economy, and Taxation*; Cambridge University Press (CUP): Cambridge, UK, 2014. [CrossRef]
45. Watson, M. Historicising Ricardo's comparative advantage theory, challenging the normative foundations of liberal International Political Economy. *New Politi-Econ.* **2017**, *22*, 257–272. [CrossRef]
46. Keshk, O.M.; Reuveny, R.; Pollins, B.M. Trade and Conflict: Proximity, Country Size, and Measures. *Confl. Manag. Peace Sci.* **2010**, *27*, 3–27. [CrossRef]
47. Matsuyama, K. Geographical advantage: Home market effect in a multi-region world. *Res. Econ.* **2017**, *71*, 740–758. [CrossRef]
48. Allen, T.; Arkolakis, C. Trade and the Topography of the Spatial Economy. *Q. J. Econ.* **2014**, *129*, 1085–1140. [CrossRef]