Research on the Interrelationship of Sustainable Development Goals Based on Multilayer Network Modeling

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Abstract. The Sustainable Development Goals are not just a call to action, but a vision of hope for a better world. To achieve sustainable development, it is critical to study relationship between SDGs and select the most effective priority goals. A multi-layer network approach was employed to establish a model for analyzing the interrelationships and impacts of SDGs.The ffnal model was derived by computing the Pearson correlation coefffcient matrix and network connections. The network models for 10 regions were visualized, revealing that in the WLD region, SDG8 had a positive impact on other SDGs, particularly on SDG4, while SDG17 had a negative impact on 14 SDGs.We have concluded that our model has strong robustness, high stability, and good interpretability. This provides scientiffc guidance and support for achieving the SDGs.

Keywords: SDG, Multiple Complex Networks, Pearson Correlation Coefficient Matrix.

1. Introduction

To promote sustainable development for all humanity, the establishment of the Sustainable Development Goals (SDGs) embodies humanity's hope for the future. Sustainability is a concept understood intuitively by all but very difficult to express in concrete, operational terms.[1,2,3,4] Brundtland's seminal definition [5] serves as a springboard for a variety of interpretations that emphasize the issues of needs, limits on development, futurity, inter- and intra-generational equity and the simultaneous fulfillment of economic efficiency, environmental protection, and social justice goals. Although the term is accompanied by imprecision, ambiguity, and, at times, contradictions, there is a generally accepted understanding of what sustainable development means.[6]

The interrelatedness,mutual support or opposition between these goals affects the implementation of all of them. In addition, international events such as technological advances, global pandemics, war, and refugee crises also have a signiffcant impact on the implementation of SDGs. Therefore, interdisciplinary and comprehensive research methods are needed to understand and address these complex relationships and impacts.

Our main challenge is to develop a network model that describes the relationships between the seventeen Sustainable Development Goals (SDGs), and to use this model to support decisionmaking and assess potential impacts. Includes the construction of a network structure describing the relationships among the seventeen SDGs. Using the network structure to evaluate the effectiveness of a single SDG in promoting business development, and determining the priority issues and achievable goals within the next ten years. To explore the impact of achieving a speciffc SDG on the network structure, as well as how achieving that SDG would inffuence priority setting decisions, and to discuss other SDGs that could be incorporated into the United Nations agenda. To discuss the impact of international events such as technological advances and global pandemics on the network structure and priority setting decisions, and to examine the implications of such disruptions for sustainable development. To promote the method of constructing network structures to other companies and organizations to help them determine the priority of their goals.

The sustainable development goals (SDGs) are tightly interconnected and constitute an indivisible whole, making it crucial to study their interrelationships. There has been extensive research conducted by various sectors of society on the relationships between SDGs. In 2015, the United Nations proposed 169 speciffc targets to elaborate the 17 goals. And the International Council for Science has used network models to study the interconnections between goals. Other scholars have conducted research from different perspectives, such as linkage pathways, degree of interaction, sustainable development goal models and execution methods. They have achieved many results.[1] However, current research has certain limitations because it is limited to expert knowledge and does not fully utilize economic data. Moreover, there is still a lack of quantitative research on how to use the relationships between SDGs to prioritize goals.

According to the requirements of the task, our work mainly includes the following aspects:

• Data collection and preprocessing: We collected 169 targets and 241 indicators data from UN experts, as well as time-series data of 500 sustainable development indicators from 1967 to 2018, covering ten research regions.

• Model establishment: Based on the correlation between data and the 4-layer network structure from goals to data, we constructed the SDG relationship network model. Using the relationship network model G, we proposed an evaluation method to assess the effectiveness of prioritizing the implementation of a particular SDG.[8]

• Model application: Based on the established network model, we visualized the network graph of ten research regions. Using the evaluation method, we also visualized the effectiveness of prioritized strategies for ten regions. Analyzing the visualization results, we drew conclusions. Based on the network model, we established a model to describe the impact of different timeframes on the degree of SDG implementation. We established a model for the SDGs that can be reasonably achieved in different regions within ten years.

• Model adjustment for implementing a speciffc SDG: Based on the network model, we modiffed the weight and adjusted the network model, considering the impact on selecting priority items. We also proposed some new goals that could be included in the UN’s considerations, such as technological development and digitalization, and analyzed the reasons from the perspective of other SDG impacts.

• Model adjustment during international crises or opportunities: Based on the network model and evaluation method, we derived a new relationship network G’, introduced the anti-interference index c, and proposed a relationship formula between the disturbance Δx and G’ and the original network G. We modiffed the network model, considering the impact on selecting priority items, and analyzed the impact on the UN’s mission before and after the crisis.

• Promotion of model analysis methods: We promoted the analysis method of the relationship network to other ffelds, such as analyzing the relationship between a company’s strategic goals, to help leaders prioritize development items. We conducted robustness and stability analysis, considering the disturbance of different research regions and events on the model. We concluded that the model has strong stability and robustness. In addition, we also analyzed the advantages and disadvantages of the model.

Our workflow diagram is shown in Figure 1:

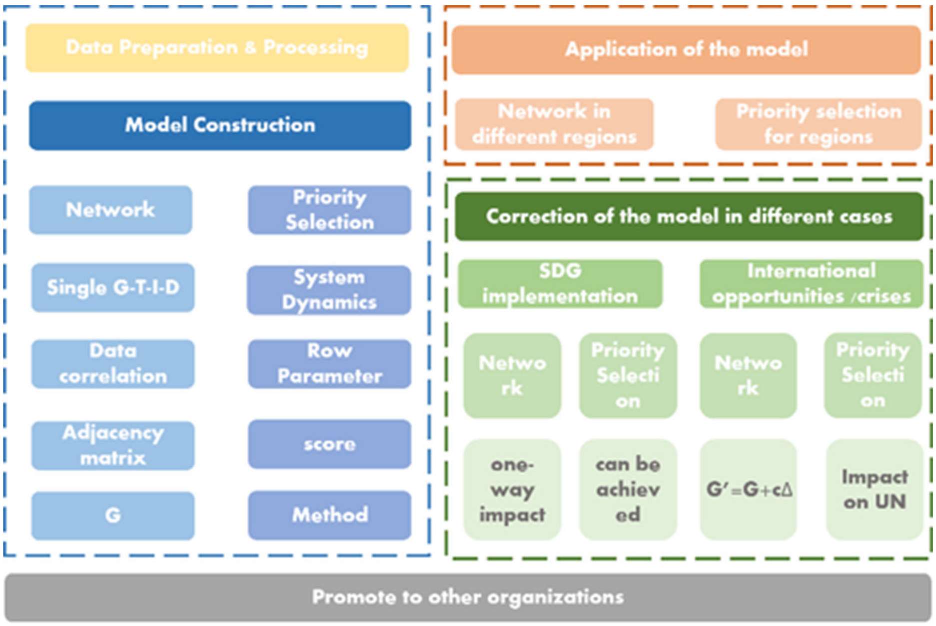

Figure 1 Our work

2. Multiple Complex Model for Interactions among SDGs

2.1. Notations

The notation used in this paper is shown in Table I:

Table 1 Notations used in this paper

Symbol	Description	Unit
N	Nodes, e.g. Ng denotes the set of Goal nodes	N_g , N_t , N_i , N_d .
A	Adjacency matrix	A_{gg} , A_{tt} , A_{ii} , A_{dd} , etc.
G	Relationship Network Model	G = Agg .
x	The degree of realization of SDGs , as a 1×17 matrix	x_0 , x_1 , etc.
Δx	Perturbations arising , for 1*17 matrix	Δx
c	Anti-interference coefficient, related	c

2.2. Introducing Multiple Complex Networks

Multilayer Complex Networks (MCNs) refer to complex network models composed of multiple layers or networks, which can interact or depend on each other. Unlike traditional network models, multilayer complex networks allow different types of nodes and connections to intersect across different layers, and allow nodes to have overlapping relationships across different layers.

Multilayer complex networks have wide applications in describing and analyzing complex real-world systems, such as social networks, biological networks, and transportation networks. They can provide a more comprehensive perspective to describe the structure and function of the system, and can better capture the multiple relationships between nodes.

Analytical methods of multilayer complex networks include graph-theoretical methods, complex network models and methods, as well as machine learning methods, among others. By an- alyzing multilayer complex networks, we can better understand the evolution and behavior of the system, and provide new insights and methods for solving practical problems.

In summary, the study of multilayer complex networks has great potential for understanding complex systems and addressing real-world problems. The development of analytical methods and models for multilayer complex networks can provide a new perspective and approach for the study of complex systems.[9]

2.3. Analyzing Relationships among SDGs using Multilayer Complex Networks

The interrelationships among SDGs are highly complex, as each goal can potentially affect the implementation of other goals.[10] Moreover, there are many indicators that can be used to represent the degree of goal attainment, and simply linking goals to data indicators may overlook their intricate relationships.[11] Therefore, we turn to a data-driven approach, namely MCNs, to analyze the relationships among data indicators, which can indirectly construct the interrelationships among SDGs. This approach can help us better understand the mutual impacts among SDGs and provide new ideas and methods for solving practical problems.

- **G − T − I framework determined by UN experts:**

The United Nations has identified 169 specific indicators to assess whether the 17 sustainable development goals (SDGs) have been achieved. For instance, SDG7 is evaluated using seven indicators, including increasing the proportion of renewable energy and improving energy efficiency. UN experts have established links between Targets and used Indicators to quantify them. For example, Target 1.1 under SDG1 (no poverty) is ”to eradicate extreme poverty and hunger globally,” while Target 1.2 is ”to ensure that everyone has access to adequate social protection and healthcare.” Indicator 1.1.1 under Target 1.1 is ”Proportion of population below the international poverty line, by sex, age, employment status and geographical location (urban/rural).”Based on the G − T − I system established by UN experts and known data, we can establish a direct relationship between World Bank Data and Indicators. This allows us to present the changes between goals and data more systematically. By connecting 241 Indicators with 500 Data indicators, we ultimately obtained 17 isolated G − T − I − D networks. Using SDG9 as an example, the network structure is shown in Figure 2.

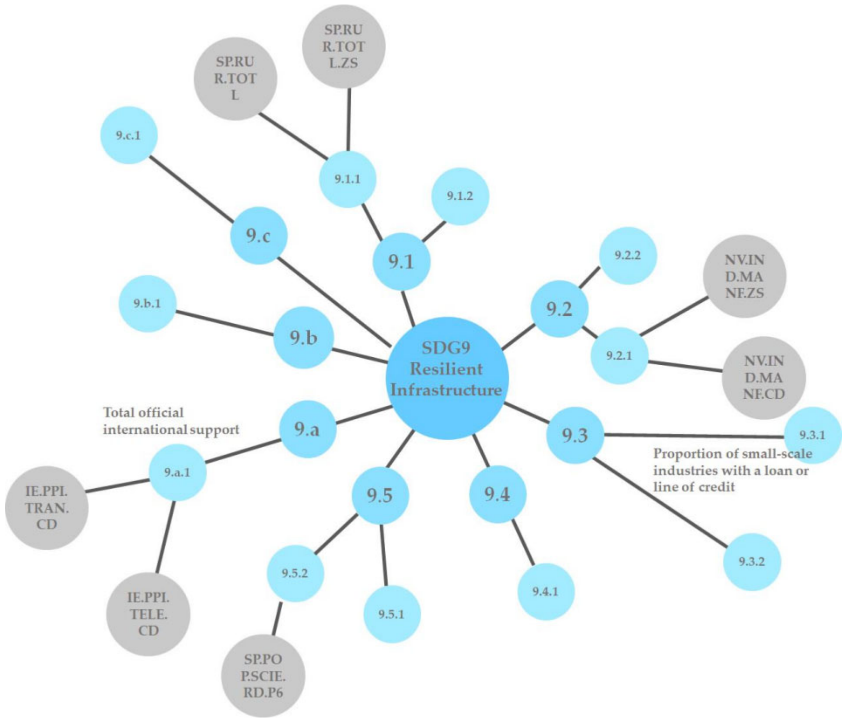

Figure 2 G − T − I − D network

- **Describing the Mechanism of Interconnection in the G-T-I-D Network:**

As shown in Figure 4, two G−T −I−D networks are connected through the correlation of D. N represents the node matrix, with N_g , N_t , N_i , N_d representing the goals, targets, indicators, and data nodes, respectively. A represents the adjacency matrix, with A_{gg} [17×17], A_{tt} [169×169], A_{ii} [241 × 241], A_{dd} [500 × 500] representing the adjacency matrices between goals, targets, indicators, and data, respectively. A_{gt} [17 × 169], A_{ti} [169 × 241], and A_{id} [241 × 500] represent the adjacency matrices between goals and targets, targets and indicators, and indicators and data, respectively. The adjacency matrices of these four initial ones matrices are given by a single G − T − I − D structure.

The linking of the Datas is based on the Pearson correlation coefficient values. (the datas were connected when the r exceeded 0.9 with $p < 0.1$ significance level.)

Two G - T - I - D networks as shown in Figure 3

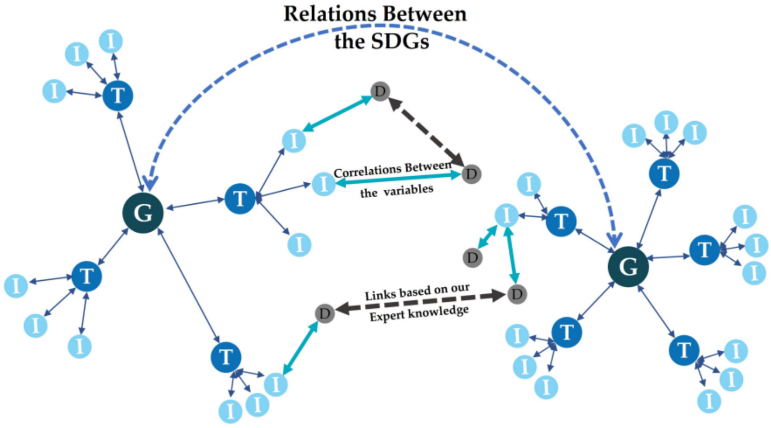

Figure 3 two G − T − I − D networks

• **Calculation of G − G Adjacency Matrix:**

First, calculate the correlation between data: We calculated the correlation coefficients between World Bank data indicators to obtain the Add matrix.

Then, the I − I adjacency matrix Aii was obtained as $A_{ii} = A_{id} \cdot A_{dd} \cdot A_{di}$, and the T − T adjacency matrix was obtained as $A_{tt} = A_{ti} \cdot A_{id} \cdot A_{dd} \cdot A_{di} \cdot A_{it}$. Finally, the G − G adjacency matrix was obtained as $A_{gg}= A_{gt} \cdot A_{ti} \cdot A_{id} \cdot A_{dd} \cdot A_{di} \cdot A_{it} \cdot A_{tg}$. The process is illustrated in Figure 4.

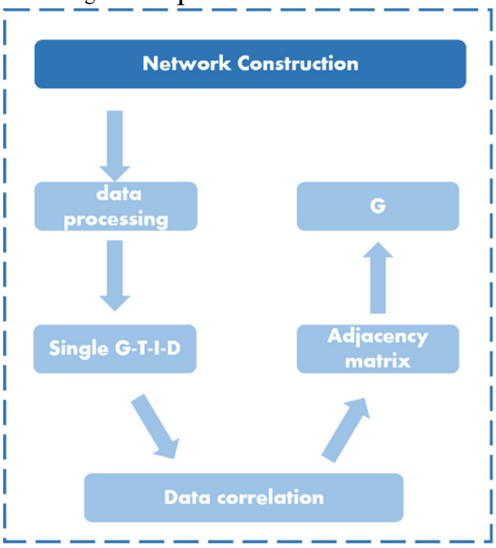

Figure 4 Calculation of Agg

3. Results

3.1. In the WLD Region

The elements of the G − G adjacency matrix Agg represent the weights that denote the interconnections among the 17 SDGs. By distinguishing only between 0 and non-zero elements, we can obtain an undirected and unweighted graph of the SDGs, which represents the existence of inffuence between two SDGs. If we consider the weight values, the greater the absolute value, the higher the degree of inffuence between two SDGs, with the sign indicating mutual support or counterbalance between the two SDGs. We use orange-red and light-blue colors to represent the mutually supportive and antagonistic relationships between SDGs, respectively, and the brightness of the connecting line color indicates the degree of inffuence between SDGs. We visualize the SDG impact network as shown in Figure 5 after optimizing its structure.

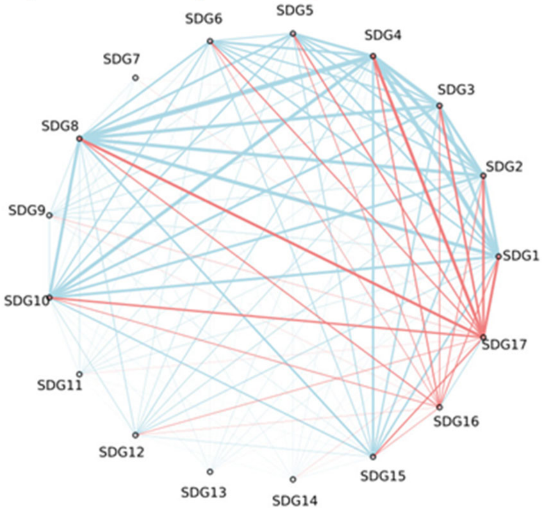

Figure 5 Weighted graph of SDGs interconnection (using WLD as an example)

3.2. In Different Regions

Considering that the connections and inffuences between SDGs in different regions may vary,we used data from different regions to verify the generated network structure. The SDG networksof eight regions are shown in Figure 6.

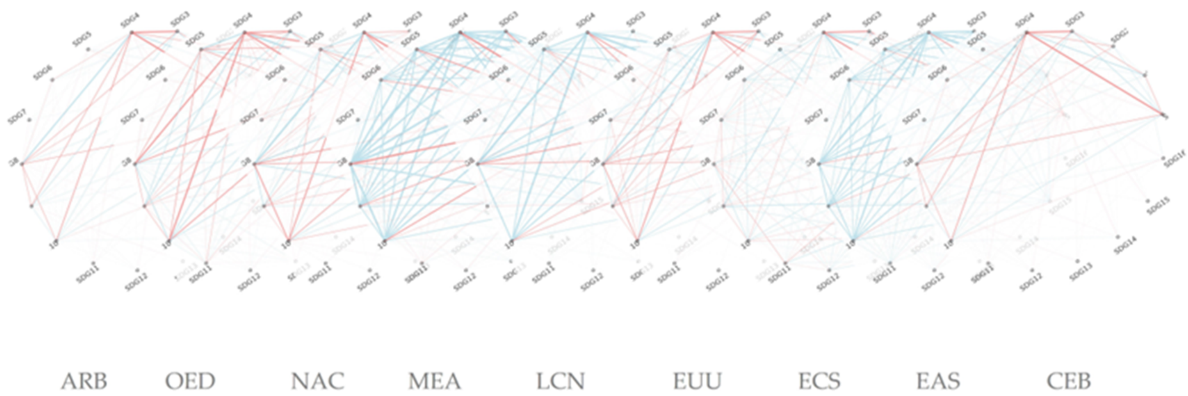

Figure 6 Weighted graph of SDGs interconnection (using WLD as an example)

In the CEB region, SDG4 has a negative impact on six other goals, including SDG3, and onlya positive impact on SDG8. On the other hand, in the EAS region, SDG4 has a positive impacton all 16 SDGs. In the OED region, most of the SDGs have negative impacts on each other, whilein the MEA region, most of the SDGs have positive impacts on each other. The reasons for thesediferences may be related to various factors, such as economic, social, cultural, and political dif-ferences.

In the CEB region, a lack of educational and health resources may be the reason for the negativeimpact of SDG4 on other goals. For instance, a shortage of education and health resources couldlead to higher levels of disease and poverty, thereby having a negative impact on SDG3.

On the other hand, in the EAS region, success in education and health may be the reason forthe positive impact of SDG4 on other goals. For example, good levels of education and health mayhelp to improve employment rates, promote economic growth, and thus have a positive impact on SDG8.

4. Conclusions

We have concluded that our model has strong robustness, high stability, and good interpretability.This provides scientiffc guidance and support for achieving the SDGs. In this model, we conducted a regional test by setting up different regions to check the stability of the model in different regions. We have considered the knock-on effects between the SDGs, which is more realistic and more accurately reflects the interlinkages between the SDGs.It is more in line with the reality and more accurately reflects the interconnections among the SDGs.The network is complex, hierarchical, interpretable and easy to understand.The model is highly universal and can be extended to other fields or aspects.It is stable and robust, indicating that the model is unlikely to be affected by outliers or unexpected changes.The model is stable and robust, indicating that the model is unlikely to be affected by outliers or unexpected changes.

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