Problem Chosen	2023 MCM/ICM Summary Sheet	Team Control Number
D		2315167

Prioritizing the UN Sustainability Goals

Summary

The Sustainable Development Goals (SDGs) are a set of 17 interrelated goals that aim to thoroughly address the social, economic, and environmental aspects of development in an integrated manner. In this paper, we analyze the interrelationships and development priorities among these 17 goals by modeling the network of relationships among them.

In Task 1, to establish the network between 17 SDGs, we import two indicators as global **GDP and HDI**, weight and combine them into one dependent variable of 17 SDGs. Then we collect data of detailed statistics concerning 17 SDGs' sub-goal from authorized resources like OECD and UNDP. With the help of literatures and experts, we use **Analytic Hierarchy Process (AHP)** to establish the judging matrix to quantify the quantitative results of each goals. Afterwards, we use **random forest regression and adaboost regression**, hence derive the separate weight between the 17 independent variables (SDGs) and the indicator variable. Based on the **Spearman correlation coefficient model**, we built the correlation coefficient matrix of 17 goals. Then we exploit **Google Pagerank Algorithm** to clarify the inner relationship between 17 SDGs. Combining the inner relationship and separate weights in the model, we finally construct the eventual network model and calculated the importance index for each goal to measure its importance and priority.

In Task 2, we identified the goal with the highest importance index, **SDG 7: Affordable and Clean Energy**, as the priority that most effectively advances the work of the United Nations, based on the relational network and Google PageRank algorithm in question one. By building **linear regression models** for each SDG quantitative indicator, its value is inferred for the next decade. With no change in total resources, we assigned partial weights of the remaining 16 targets to SDG 7 to represent the change in the UN after advancing SDG 7, and calculated significant indices of GDP and HDI for each of the next ten years before and after advancing SDG 7. Comparing the results, we find that the GDP and HDI indices in the first year after prioritizing advancement increase by **8.84%** compared to the year without prioritizing advancement, and gradually increase to **10.32%** over the ten-year period.

In Task 3, to simulate that a SDG has been fully achieved, we set the quantitative result for that SDG to 0, concurrent with the impact on associated SDGs. Based on the **correlation coefficient matrix**, we calculate the quantitative results of the remaining SDGs after achievement. The results can be divided into two categories: **association-enhanced and association-diminished**. We find that the correlation between some SDGs decreases when SDG 8: decent work and economic growth are fully achieved, and the correlation between the remaining 16 SDGs increases when other SDGs than SDG 8 are fully achieved. Finally, based on these results, we propose five new goals.

In Task 4, there are some disturbances which is not encompassed do have some underlying relationship among SDGs and 2 indicators. Supported by data, we have the conclusion that these events will considerably influence associated SDGs. Some seemingly unimportant elements will steeply decrease once the disturbance arise, which UN should attach more significance.

Finally, we review the advantages and shortcomings of the modeling process and summarize replicable experience and models that provide ideas for other businesses and organizations to establish priorities.

Keywords: SDGs, Random Forest Model, AHP, Relationship network

Contents

1 Introduction

1.1 Problem Background

The Sustainable Development Goals (SDGs) are the 17 global development goals set by the United Nations. It aims to achieve sustainable development by thoroughly addressing the three dimensions of development - social, economic and environmental - in an integrated manner. These seventeen development goals are interrelated in the sense that the development of one goal may have a positive or negative impact on other goals. This makes the achievement of all the goals a precarious process. In addition, unforeseen events such as global pandemics, climate change and regional wars can have a serious impact on the Goals. Considering funding constraints and international priorities, the UN needs to select the most effective goals for priority development.

Figure 1: Sustainable Development Goals

1.2 Restatement of the Problem

In order to accomplish these seventeen goals more efficiently, we need to complete the following tasks.

Task 1. Collect data from previous years. Select quantitative indicators for each of the seventeen targets separately and quantify them.

Task 2. Building a network of relationships between the seventeen SDGs.

Task 3. Use the above network of relationships to identify the priorities that will most effectively advance the work of the United Nations. Give criteria for assessing the effectiveness of the priorities. And predict what can be achieved in the next ten years once the priorities have been set in motion.

Task 4. Give the new network structure that emerges when a sustainable goal is achieved. Judge the impact of this achievement on the selection of priorities and whether the UN needs to incorporate other new goals.

Task 5. Discuss the impact of technological advances, international pandemics, climate change, regional wars, refugee movements or other international crisis events on the networks of relationships and priority choices described above. Answer what impact these contingencies have had on progress towards the UN Sustainable Development Goals from a network perspective.

Task 6. Discuss the prospects of applying our networking approach in other companies or organisations.

1.3 Our work

The following figure is a brief summary of our work:

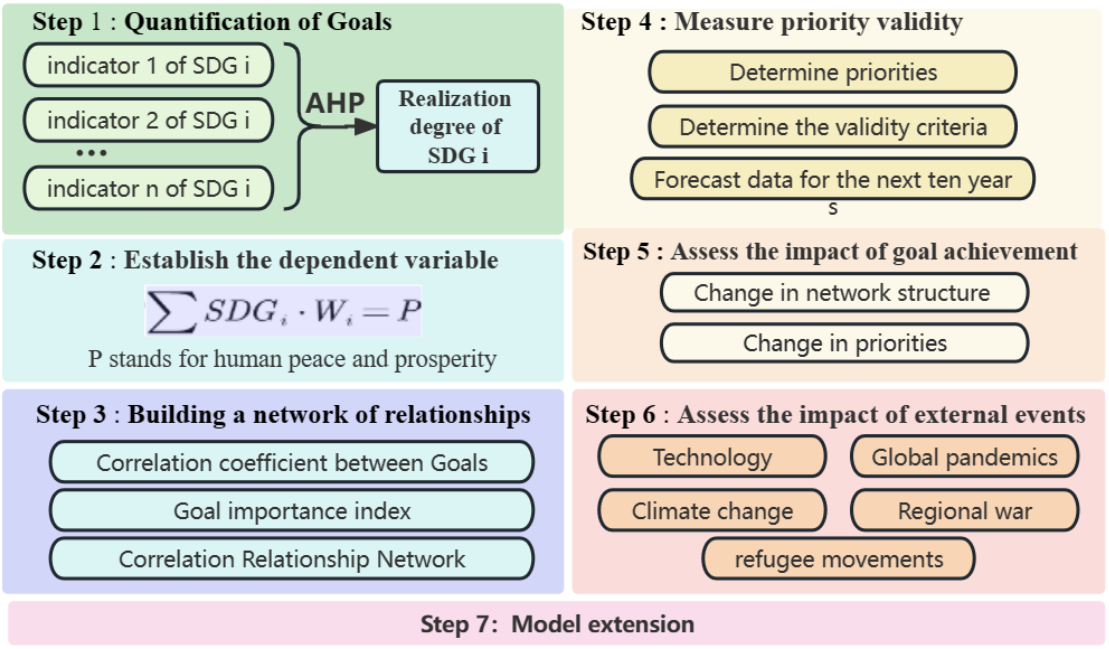


Figure 2: The frame of this paper

2 Assumptions and Justifications

To simplify our model, we make the following basic assumptions, each of which is properly justified.

- **The global statistics collected by UNDP, World Bank, World Intellectual property organization, WTO and other official organizations are accurate.**
  Since all our data are collected from official websites and databases, we assume the accuracy of our data. The reliability of global data from these large official organizations should be high.
- **Expert scoring does not distinguish between the professional level of experts.**
  There will be several experts to score in AHP, whose professionality is assumed to be identical.
- **When establishing the model between SDGs and the dependent variable, indicators that are relatively unimportant are neglected.**
  According to the Pareto principle, for many outcomes, roughly 80% of consequences come from 20% of causes. To construct the model, we concentrate on 17 SDGs and world GDP and HDI.
- **In predicting future developments, we assume that the external environment is stable, free from major natural disasters, disease or large-scale global wars.**
  Natural disasters, global pandemics and large-scale wars are rare and difficult to predict. To simplify our model, in task 2, we assume that this will not happen in the next ten years.

3 Notations

The primary notations used in this paper are listed in Table 1.

Table 1: Notations of our paper

Symbol	Definition
X_{ij}	The quantitative results of goal i in year j. (Not normalized)
X^*_{ij}	The quantitative results of goal i in year j. (Normalized)
W_{Gi}	The weight of the i-th Goal.
P	Indicator to measure global human peace and prosperity.
x_{ij}	The value of indicator i in year j.
w_{ij}	The weight of indicator i in year j.
I_i	Importance Index of SDG i.
E_Ci	EigenVector Centrality of SDG i.
D_Ci	Degree Centrality of SDG i.
$\rho_{X,Y}$	Pearson correlation coefficient.
ρ	Spearman correlation coefficient.

4 TASK 1: SDG Relationship Network Model

4.1 Quantification of goals

In the absence of data that would quantify the extent to which each target has been achieved, we need to quantify the targets through a set of quantitative indicators.

For each goal, multiple quantitative indicators were selected and relevant data was found for each indicator for the period 2000-2020. Through hierarchical analysis (AHP), weights for the indicators were determined to quantify the targets.

Due to space constraints, we have chosen **GOAL 8: Decent Work and Economic Growth** to demonstrate a specific quantitative process.

1. According to the UN website (2023), Goal 8 has twelve specific targets, and the first five of which are more important.

Table 2: Specific targets for the Goal 8

Target	Summary of content
Target 8.1	GDP growth in LDCs is at least 7% per year.
Target 8.2	Achieving higher levels of economic productivity.
Target 8.3	Promote development-oriented policies.
Target 8.4	Improve resource efficiency in global consumption and production.
Target 8.5	Enable all people to have decent work and equal pay for equal work.

2. Referring to the contents of the target, we found the corresponding data.

i) Annual growth rate of real GDP per capita.

Year	2000	2005	2010	2015	2020
Percentage(%)	3.1	2.8	3.3	1.9	-4.4

Source: National Accounts Statistics (2023)

ii) Annual growth rate of real GDP per employed person.

Year	2000	2005	2010	2015	2020
Percentage(%)	2.5	2.1	3.3	1.7	-0.6

Source: ILO modelled estimates, November 2021, ILOSTAT, International Labour Organization (ILO).

iii) Material footprint per unit of GDP (Kilograms per unit of constant 2015 United States dollars)

Year	2000	2005	2010	2015	2020
Quantity(kg)	1.19	1.20	1.22	1.22	1.14

Source: World Environment Situation Room, United Nations Environment Programme (UNEP).

iv) Unemployment rate

Year	2000	2005	2010	2015	2020
Percentage(%)	5.8	5.9	5.9	5.6	6.6

Source: ILO modelled estimates, November 2021, ILOSTAT, International Labour Organization (ILO).

Note:Remember to convert all larger is better metrics to smaller is better metrics and dimensilessize the data.

- Consistent processing: $X_i^* = Max(X) - X_i$
- Dimensionless processing: $X_i^* = \frac{X_i}{\sqrt{\sum_{j=1}^{n} X_j^2}}$

3. To obtain the corresponding weights for each indicator, we constructed a subjective evaluation matrix and scored the indicators based on their importance.

$$\begin{array}{c} \\ i \\ ii \\ iii \\ iv \end{array} \begin{array}{c} \begin{array}{cccc} i & ii & iii & iv \end{array} \\ \begin{pmatrix} 1 & 0.25 & 0.25 & 2 \\ 4 & 1 & 1 & 8 \\ 4 & 1 & 1 & 8 \\ 0.5 & 0.125 & 0.125 & 1 \end{pmatrix} \end{array}, \tag{1}$$

The matrix above is a 4 × 4 square matrix, which we denote as A and the corresponding elements as a_{ij} . This square matrix has the following characteristics:

- a_{ij} indicates the significance of i compared to the indicator j.
- $a_{ij} > 0$,and satisfy $a_{ij} \times a_{ji} = 1$

To ensure that there are no logical errors in the evaluation system, we need to perform a consistency check on the matrix:

(a) Calculation of consistency index CI:

$$CI = \frac{\lambda_{\max} - n}{n-1}$$

(b) Find the corresponding average random consistency index RI. When $n = 4$, $RI = 0.89$

(c) Calculate the consistency ratio CR.

$$CR = \frac{CI}{RI}$$

If $CR < 0.1$, the consistency of the judgment matrix can be considered acceptable; otherwise, the consistency of the judgment matrix needs to be corrected.

If the consistency of our judgment matrix is acceptable, then we can imitate the method of finding the weights of the consistent matrix.

Step 1: Find the maximum eigenvalue of matrix A and its corresponding eigenvector.

Step 2: Normalize the eigenvectors to get our weights.

The following is the result of the operation of Goal 8:

Table 3: Weight of each indicator for Goal 8

item	Eigenvector	Weight value(%)	Maximum characteristic root	CI value
i	0.595	10.526	4	0
ii	2.378	42.105		
iii	2.378	42.105		
iv	0.297	5.263		

4. According to the index weights and the processed data of each index, we obtained the target quantified data by weighted average:

$$X_j = \sum_{i=1}^{n} x_{ij} w_{ij}$$

- X_j represents the quantitative result of this goal in year j.
- x_{ij} represents the value of indicator i in year j.
- w_{ij} represents the weight of indicator i in year j.
- n represents the goal with n quantitative indicators.

To ensure that the quantitative results are of the same order of magnitude for different Goals, we need to normalize them.

$$X_j^* = \frac{X_j}{\sum X_j}$$

Repeating the above process 17 times, we obtained the quantified data of all seventeen targets (see Table 4 for details). The smaller the value of the indicator, the higher the completion of the target.

Table 4: Quantitative data for the seventeen goals

Goal	2000	2005	2010	2015	2020
No Poverty	0.3326	0.2526	0.2042	0.1498	0.0609
Zero Hunger	0.2535	0.2484	0.2005	0.1867	0.1928
Good Health and Well-being	0.2242	0.2100	0.2003	0.1878	0.1777
Quality Education	0.3794	0.2934	0.1327	0.1140	0.0804
Gender Equality	0.3262	0.2683	0.2072	0.1404	0.0579
Clean Water and Sanitation	0.3673	0.3030	0.2461	0.0783	0.0053
Affordable and Clean Energy	0.3148	0.2949	0.2108	0.1297	0.0498
Decent Work and Economic Growth	0.1350	0.1516	0.0910	0.1070	0.5154
Industry, Innovation and Infrastructure	0.2853	0.2971	0.2048	0.1199	0.0929
Reduced Inequality	0.2181	0.2843	0.2202	0.2309	0.0466
Sustainable Cities and Communities	0.2256	0.2176	0.2039	0.1779	0.1750
Responsible Consumption and Production	0.2350	0.2252	0.2139	0.1841	0.1418
Climate Action	0.2071	0.2113	0.2009	0.1923	0.1884
Life Below Water	0.2356	0.2147	0.1832	0.2042	0.1623
Life on Land	0.4319	0.3126	0.1623	0.0178	0.0754
Peace and Justice Strong Institutions	0.1997	0.2019	0.2011	0.2011	0.1961
Partnerships to achieve the Goal	0.2036	0.2062	0.1961	0.1995	0.1946

4.2 Construct the dependent variable

The Sustainable Development Goals (SDGs) are a collection of 17 interrelated goals that serve as a "common blueprint for peace and prosperity for people and the planet, now and in the future". Therefore, we have chosen the Human Development Index (HDI) and total global GDP as indicators of the degree of human peace and prosperity.

Table 5: Human Development Index (HDI)

Year	2000	2005	2010	2015	2020
HDI	0.7	0.741	0.624	0.711	0.737

Table 6: Total global GDP

Year	2000	2005	2010	2015	2020
GDP(Trillion dollars)	31.85	46.45	62.87	74.91	84.01

- Global HDI data source: United Nations Development Programme, or UNDP.
- Global GDP data source: International Monetary Fund (IMF).

The global impact of the goals on economic aspects will be reflected in the change of global GDP, while the impact on human peace will be reflected in the HDI index. Synthesizing the relevant literature and the seventeen SDGs, we use $P = 0.7 \times GDP + 0.3 \times HDI$ as a measure of global human peace and prosperity as the dependent variable of the 17 independent variables.

Combining the result of random forest regression and adaboost regression, we derived the relationship between the 17 independent variables (SDGs) and the dependent variable. The significance of the independent variables was obtained.

Table 7: Influence weight of SDGs on the dependent variable

Goal	Goal Weight
SDG2: Zero Hunger	7.50%
SDG4: Quality Education	7.31%
SDG7: Affordable and Clean Energy	7.22%
SDG12: Responsible Consumption and Production	7.20%
SDG5: Gender Equality	7.03%
SDG9: Industry, Innovation and Infrastructure	6.51%
SDG1: No Poverty	6.28%
SDG11: Sustainable Cities and Communities	6.25%
SDG14: Life Below Water	6.21%
SDG15: Life on Land	6.00%
SDG3: Good Health and Well-being	5.66%
SDG13: Climate Action	5.61%
SDG8:Decent Work and Economic Growth	5.27%
SDG6:Clean Water and Sanitation	4.94%
SDG17: Partnerships to achieve the Goal	4.56%
SDG16: Peace and Justice Strong Institutions	3.29%
SDG10: Reduced Inequality	2.38%

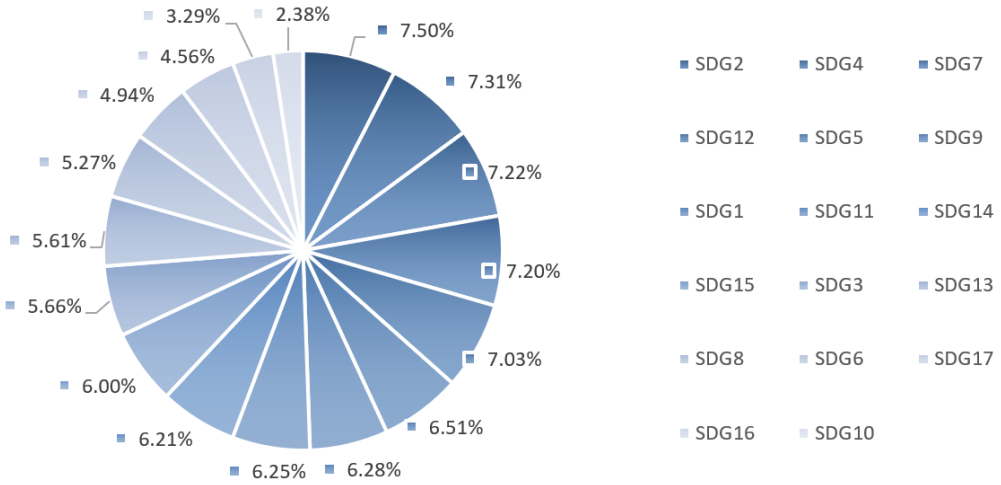


Figure 3: The importance of the seventeen SDGs

The formula expression is as follows:

$$P = 0.7 \times GDP + 0.3 \times HDI = \sum_{i=1}^{17} X_i^* W_{Gi}$$

- X_i^* represents the value of the i-th Goal.
- W_{Gi} represents the weight of the i-th goal.

Model evaluation results:

Table 8: Results of the model evaluation

	MSE	RMSE	MAE	MAPE	R^2
training set	0	0.01	0.009	4.707	0.95

The above table shows the prediction evaluation metrics of the cross-validation set, training set and test set, which measure the prediction effectiveness of random forest through quantitative metrics. Among them, the evaluation metrics of the cross-validation set can be used to continuously adjust the hyperparameters to obtain a reliable and stable model.

- **MSE (Mean Square Error)**: The expected value of the squared difference between the predicted and actual values. The smaller the value, the higher the accuracy of the model.
- **RMSE (root mean square error)**: is the square root of MSE, the smaller the value, the higher the accuracy of the model.
- **MAE (Mean Absolute Error)**: The average of the absolute errors, which reflects the actual situation of the error of the predicted values. The smaller the value, the higher the accuracy of the model.
- **MAPE (Mean Absolute Percentage Error)**: is a variation of MAE, which is a percentage value. The smaller the value taken, the more accurate the model is.
- **R^2**: The closer the predicted value is to 1, the more accurate the model is when compared to the case where only the mean is used.

With the data from the model assessment results, the model is built with a fairly high degree of accuracy and can better reflect the level of peace and prosperity of human beings. Because with only 17 SDGs as well as HDI, GDP obviously cannot fully cover all aspects of human society, it is reasonable and inevitable that the model has some bias.

4.3 Building a network of relationships

4.3.1 Calculate the correlation coefficient

1. **Pearson correlation coefficient**

$$\rho_{X,Y} = \frac{\operatorname{cov}(X,Y)}{\sigma_X \sigma_Y} = \frac{E\left((X-\mu_X)(Y-\mu_Y)\right)}{\sigma_X \sigma_Y} \tag{2}$$

The formula can be reduced to

$$r_{xy} = \frac{\sum x_i y_i - n\bar{x}\bar{y}}{(n-1)s_x s_y} = \frac{n\sum x_i y_i - \sum x_i \sum y_i}{\sqrt{n\sum x_i^2 - (\sum x_i)^2}\sqrt{n\sum y_i^2 - (\sum y_i)^2}}. \tag{3}$$

2. **Spearman correlation coefficient**

The Spearman correlation coefficient was defined as the Pearson correlation coefficient between the rank variables. For a sample of sample size n, n raw data were converted to rank data with correlation coefficient ρ

$$\rho = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2 \sum_i (y_i - \bar{y})^2}}. \tag{4}$$

We used the Spearman correlation coefficient to calculate the correlation coefficient matrix between the 17 goals. Here, due to space constraints, we only show correlations between the first seven sets of goals.

Table 9: The correlation between the first seven sets of goals

	SDG1	SDG2	SDG3	SDG4	SDG5	SDG6	SDG7
SDG1	1.0000	0.8603	0.9933	0.9272	0.9958	0.9709	0.9742
SDG2	0.8603	1.0000	0.9004	0.9707	0.8811	0.8684	0.8936
SDG3	0.9933	0.9004	1.0000	0.9489	0.9929	0.9787	0.9745
SDG4	0.9272	0.9707	0.9489	1.0000	0.9279	0.8874	0.9120
SDG5	0.9958	0.8811	0.9929	0.9279	1.0000	0.9844	0.9907
SDG6	0.9709	0.8684	0.9787	0.8874	0.9844	1.0000	0.9863
SDG7	0.9742	0.8936	0.9745	0.9120	0.9907	0.9863	1.0000

The correlation coefficients between these 17 goals can be shown in the heatmap below.

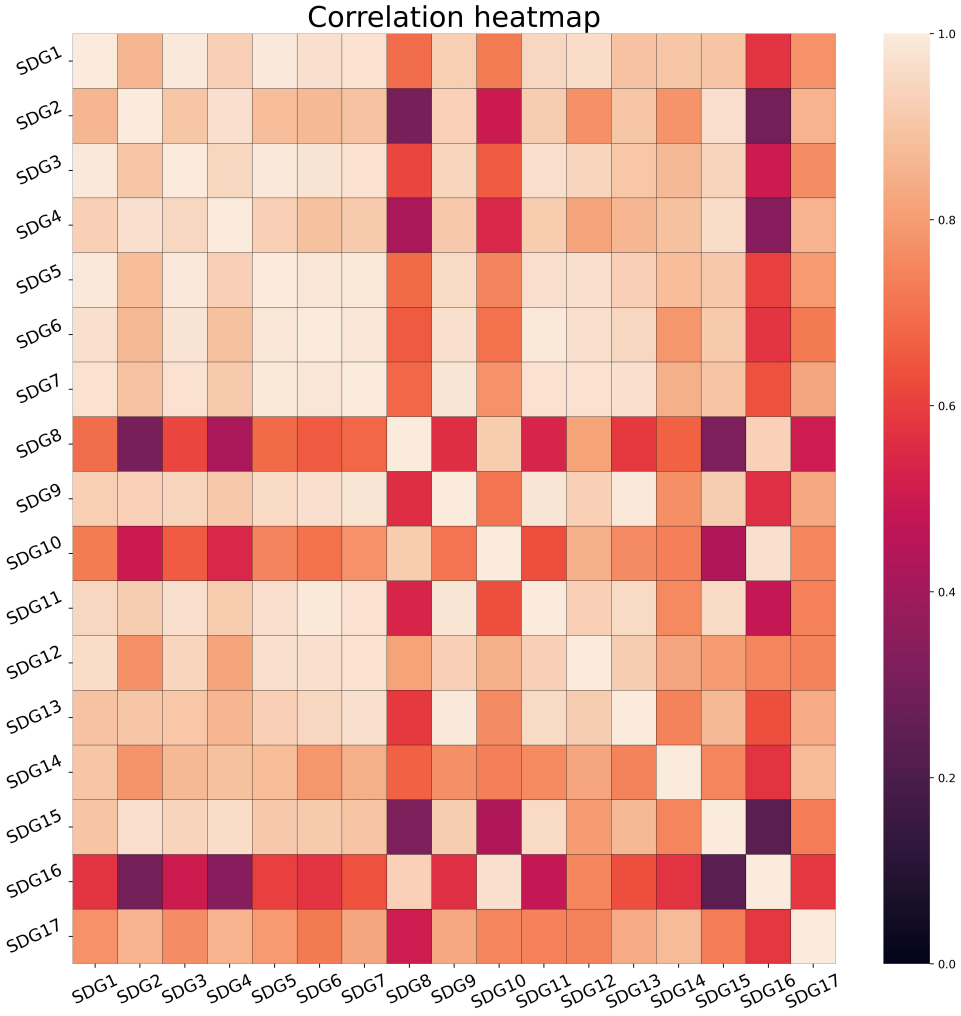


Figure 4: Correlation Heat Map

4.3.2 Calculating node importance

Here we calculate the importance of a node by some metrics

1. **Degree Centrality**

The goal weight of the indicators in Table 7 measure the importance of a goal's influence on P ($0.7 \times GDP + 0.3 \times HDI$); the higher the weight, the greater the influence, We use the value of one goal's goal weight to denote its degree centrality.

2. **EigenVector Centrality**

   The importance of a node depends not only on itself, but also on the importance of its neighboring nodes. We define the eigenvector centrality of node i as follows

$$E_C i = \sum_{j \neq i} D_C j \cdot d_{ij}$$

   - d_{ij} is the correlation coefficient between SDG i and SDG j

3. **Pagerank Algorithm**

   The PageRank algorithm considers that the result of a node's influence is the effect of superimposing its own influence with the influence of connected nodes. The algorithm principle is

$$E_{Ci} = \lambda \sum_{j=1}^{n} d_{ij} E_{Cj} + (1 - \lambda) E_{Ci}$$

According to this algorithm, we define the importance of a goal to be calculated as

$$I_i = E_C i + D_C i$$

- I_i is Importance Index of SDG i
- $E_C i$ is EigenVector Centrality of SDG i
- $D_C i$ is Degree Centrality of SDG i

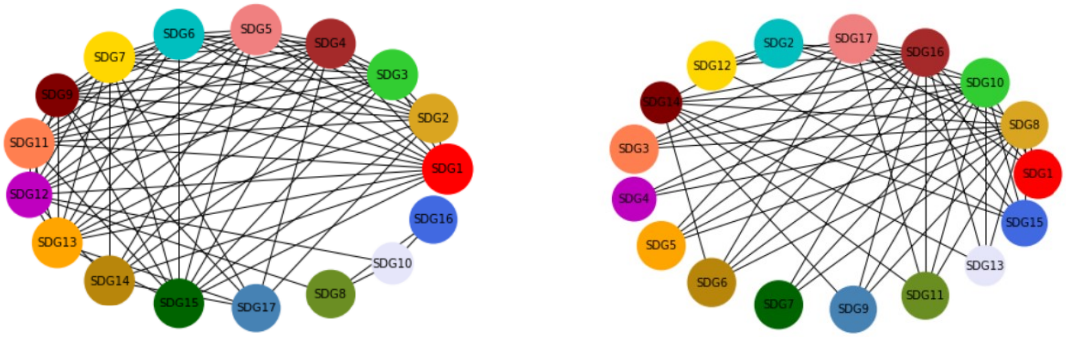
Importance Index of each Goal

Table 10: Goal importance index

name	Importance Index
No Poverty	89.6206097
Zero Hunger	82.80452326
Good Health and Well-being	89.49433054
Quality Education	85.48843807
Gender Equality	90.67933526
Clean Water and Sanitation	89.02134095
Affordable and Clean Energy	90.93702639
Decent Work and Economic Growth	61.2389819
Industry, Innovation and Infrastructure	88.80906795
Reduced Inequality	70.20553257
Sustainable Cities and Communities	88.17233216
Responsible Consumption and Production	88.07863834
Climate Action	87.29113976
Life Below Water	80.67734905
Life on Land	82.67401536
Peace and Justice Strong Institutions	56.68119759
Partnerships to achieve the Goal	77.6677601

4.3.3 Networking

Based on the correlation coefficient matrix between the goals and the importance index of each goal, we can establish the following strong-correlation relationship network(Correlation coefficient > 0.8) and weak-correlation(Correlation coefficient $\leqslant$ 0.8) network. The size of the circle is positively correlated with the size of the Importance Index of the goal.



(a) strong-correlation relationship network (b) weak-correlation relationship network

Figure 5: Correlation Relationship Network

5 TASK 2: Effectiveness measure model

5.1 Prioritization

We prioritized the goal with the highest importance index in Goal importance index Table as the one that would most effectively advance the work of the United Nations, which is SDG7: Affordable and Clean Energy.

5.2 Effectiveness

Based on the calculation principle of target importance index and the principle of Google Pagerank algorithm, this importance index can reflect not only the impact of the target itself on global GDP and HDI, but also the impact of its related goals on global GDP and HDI, and has a high effectiveness.

5.3 Building linear regression models

We build the linear regression equation for the year by least square method with Quantitative data for each target separately.

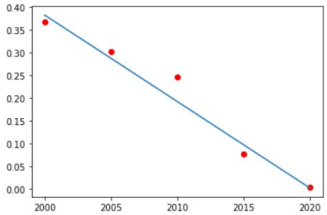


Figure 6: Examples of least square fitting

The linear equation of Quantitative data with year for the 17 targets is obtained as follows

Table 11: Linear fitting results of each SDG

SDG	**Y-intercept**(b)	**slope(k)**
No Poverty	26.179	-0.013
Zero Hunger	7.581	-0.004
Good Health and Well-being	4.828	-0.002
Quality Education	31.450	-0.016
Gender Equality	26.915	-0.013
Clean Water and Sanitation	38.343	-0.019
Affordable and Clean Energy	28.143	-0.014
Decent Work and Economic Growth	-28.594	0.014
Industry, Innovation and Infrastructure	22.792	-0.011
Reduced Inequality	16.133	-0.008
Sustainable Cities and Communities	5.868	-0.003
Responsible Consumption and Production	9.351	-0.005
Climate Action	2.467	-0.001
Life Below Water	6.514	-0.003
Life on Land	40.714	-0.020
Peace and Justice Strong Institutions	0.517	0.000
Partnerships to achieve the Goal	1.190	0.000

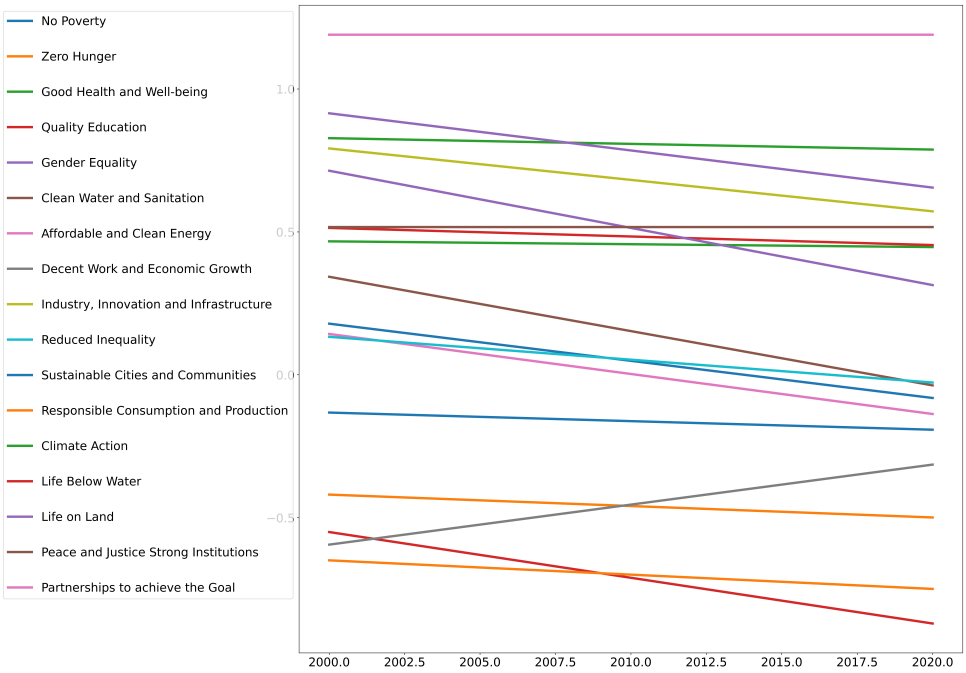


Figure 7: Linear fitting of each SDG with respect to time

5.4 Achievement in the next 10 years

We first calculate the change Ci in Quantitative data for each target from 2023 to 2032 using 17 regression equations

$$X_{ij}^{*} = k_i \cdot Y_j + b_i \tag{5}$$

- X_{ij}^{*} is the quantitative results of goal i in year j.
- k_i is the slope of the fit line for SDG i.
- Y_j is the numerical representation of the year j.
- b_i is the intercept of the SDG i fitting line

When priorities are not initiated, we calculate an index of global GDP and HDL for the year based on the value of the impact on GDP and HDI for the 17 goals in the same year. We use this index as an indicator of the effectiveness of the UN's work in that year.

$$P_j = \sum_{i=1}^{17} X_{ij}^{*} \cdot D_{Ci} \tag{6}$$

- P_j is indicators of global human peace and prosperity in year j.
- D_{Ci} is the degree centrality of SDG i.

After starting the priority: we increase the value of the impact of the target as a priority on GDP and HDI by λ and decrease the remaining targets by a total of λ proportionally, while keeping the overall work intensity constant. At this point the index of global GDP + HDL for the year is then calculated.

$$D_{Ck}^{'} = (1+\lambda) D_{Ck} \tag{7}$$

$$D_{Cm}^{'} = \frac{\left(D_{Ck}^{'} - D_{Ck}\right)}{16} + D_{Cm} \tag{8}$$

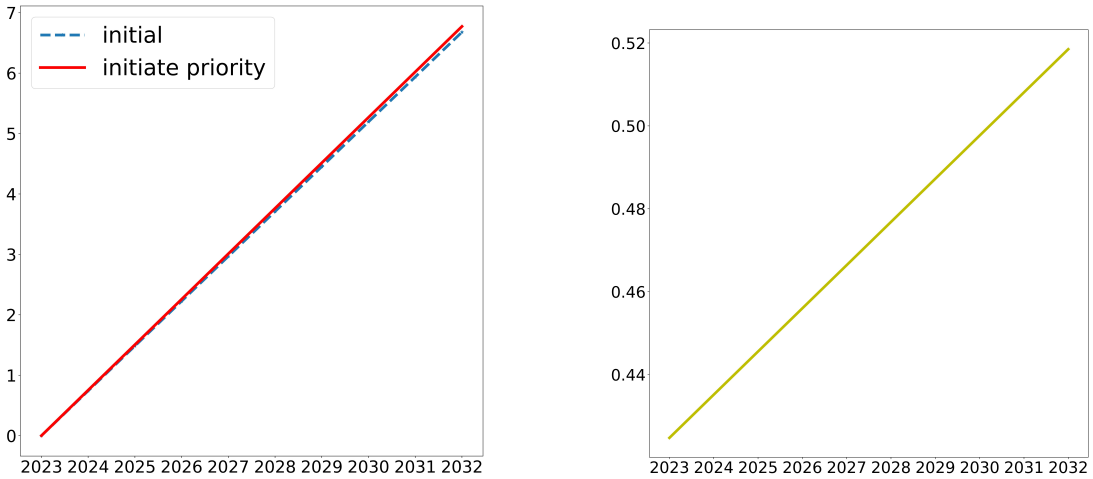
$$P_j^{'} = \sum_{i=1}^{17} X_{ij}^{*} \cdot D_{Ci}^{'} \tag{9}$$

- $D_{Ck}^{'}$ is the degree centrality of SDG k after pushing priorities.
- λ is an indicator that describes the intensity of push.
- $P_j^{'}$ is the degree of peace and prosperity j years after the promotion of priorities.

We set λ to 20% and calculate the results

Table 12: Change in the value of index P

year	initial	initiate priority
2023	4.80582	4.3811
2024	4.06371	3.62857
2025	3.3216	2.87604
2026	2.57949	2.12351
2027	1.83738	1.37098
2028	1.09527	0.61845
2029	0.35316	-0.13408
2030	-0.38895	-0.88661
2031	-1.13106	-1.63914
2032	-1.87317	-2.39167



(a) P value change diagram (b) Plot of P value increment change

Figure 8: P-value prediction graph

5.5 Results and Analysis

The P index(P = 0.7 × GDP + 0.3 × HDI) improve significantly after the priority is initiated, with an 8.84% improvement in 2023 compared to the P index without the priority initiated during the same period. The improvement increases each year thereafter, with the most significant improvement in 2032, with a 10.78% increase in P index compared to P index without prioritization at the same period.

6 TASK 3: Reconstituted relationship network structure

6.1 Data Processing

We indicate that a goal has been achieved globally by having a quantitative data X_{ij}^{*} equal to 0 for that goal. At the same time, due to the relational network structure, the achievement of that goal also leads to a decrease in the quantitative data indicator of the goal associated with it, with the magnitude of the decrease being positively correlated with the correlation coefficient.

$$X_{kj}^{'} = 0 \qquad X_{ij}^{*'} = X_{ij}^{*} - x_{kj} \cdot \rho_{ik} (i \neq k) \tag{10}$$

- k is the SDG that has been achieved.

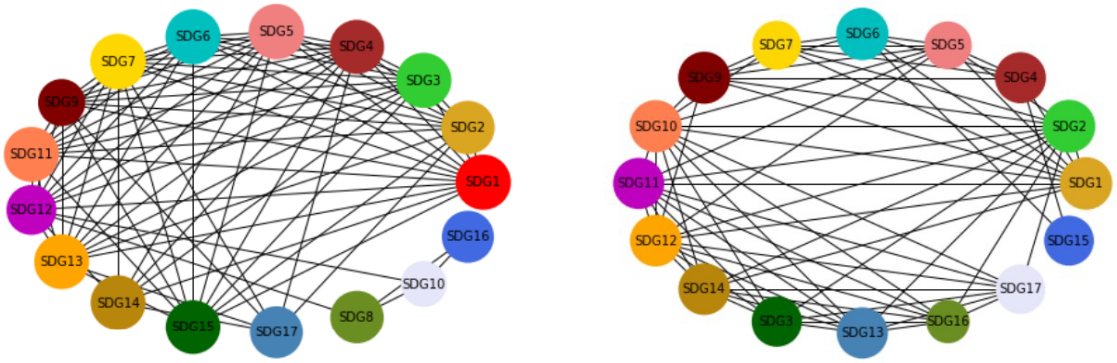
After calculating the quantitative data indicators for the remaining 16 goals by the above formula, we follow the principles and steps of Problem 1 to build the relationship networks about the remaining 16 targets and calculate the importance indices for these goals. Repeating the above process 17 times, each time achieving a different goal, we obtained 17 different sets of strong-correlation relationship networks and importance index data.

6.2 Change in relationship network structure

The obtained 17 strong-correlation relationship networks are analyzed sequentially in comparison with the original strong-correlation relationship networks, and we find that the results can be broadly classified into two categories.

1. **Association-weakening type**

   When SDG8: Decent Work and Economic Growth is fully achieved, the degree of connectivity of the relationship network of the remaining 16 goals obtained decreases, and the relationship between some of the goals changes from strong to weak correlation, mainly reflected in the decrease of correlation coefficients between SDG4, SDG5, SDG6, SDG7 and SDG12, SDG14.

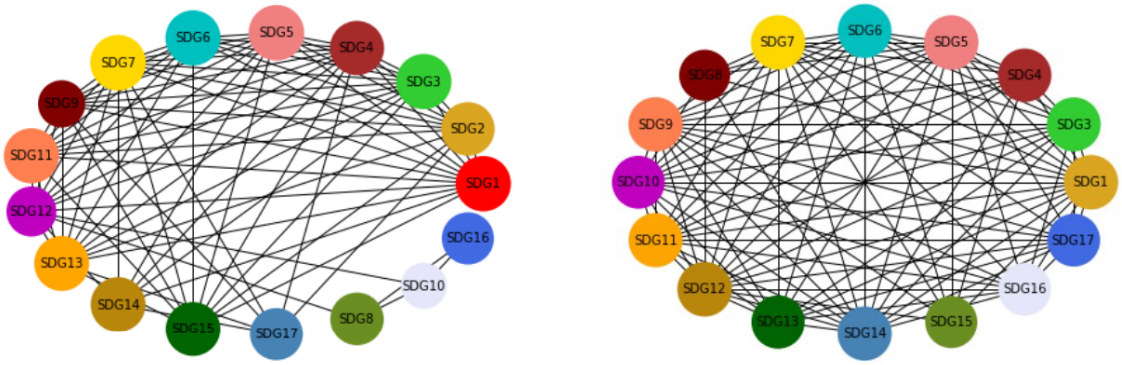


(a) Original relationship network (b) Relationship network after SDG 8 is achieved

Figure 9: Changes in the network of relationships

2. **Affiliate-Enhanced type**

   When the goals other than SDG8 are fully achieved, the connectivity of the relationship network constructed by the remaining goals increases and the correlation coefficient between all goals increases.



(a) Original relationship network (b) Relationship network after SDG 2 is achieved

Figure 10: Changes in the network of relationships

6.3 Change in priorities

- After achieving SDG1, SDG2, SDG3, SDG4, SDG5, SDG9, the priority goal shifts from SDG7 to SDG12.
- After achieving SDG6, SDG10, SDG11, SDG12, SDG13, SDG14, SDG15, SDG16, the priority goal shifts from SDG7 to SDG5.
- After achieving SDG7, the priority goal shifts from SDG7 to SDG10.
- After achieving SDG8, the priority goal shifts from SDG7 to SDG1.

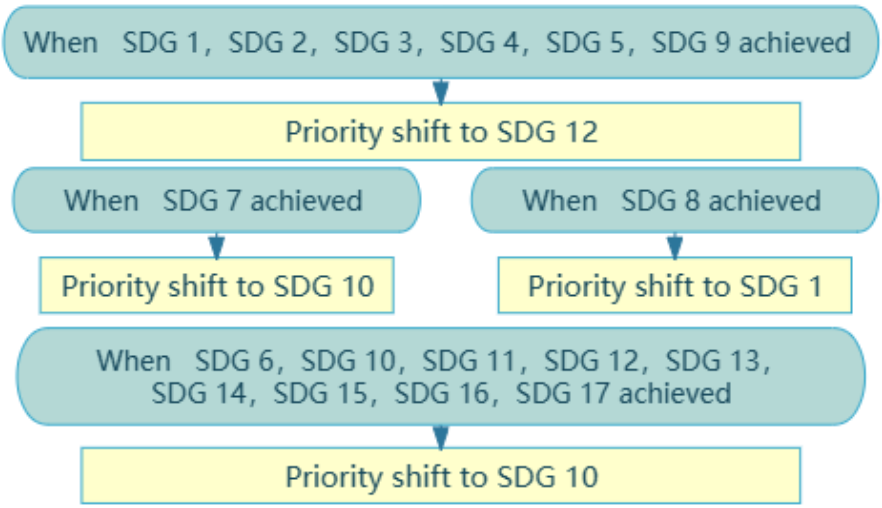


Figure 11: Priority Change diagram

6.4 Other goals to be set

- Citizen participation and governance: SDGs emphasize the establishment of a fair, just and transparent political and economic governance system. However, more goals can be set, such as increasing citizen participation, increasing government transparency, and fighting corruption.
- Anti-poverty and social inequality: Although poverty reduction is one of the SDGs, there are still many people living below the poverty line and affected by social inequality. Therefore, more specific targets can be set, such as reducing urban and rural poverty rates, improving social welfare systems.
- Digitalization and technological development: With the rapid development of science and technology, digitalization has become an important tool to promote sustainable development. Therefore, more goals can be set, such as popularizing digital technology, improving digital intelligence, promoting digital employment.
- Promote civil rights and democracy, including fighting corruption and promoting transparency, and protecting basic human rights such as freedom of the press and freedom of expression.
- Reduce traffic congestion for the urban population by building more public transportation systems and bicycle lanes, thereby reducing the use of private cars and increasing the proportion of citizens traveling by green transportation, thereby improving air quality.

7 TASK 4: Special event impact on relationship network

In real world, there are some disturbance not encompassed in our model. But these events do have some underlying relationship among SDGs and indicators. Supported by data, we have the conclusion that these events will directly and considerably influence some of SDGs and according to our network, indirectly influence other elements of the model. Some element which is less important in the model is unstable and once the disturbance arise, it will steeply decrease, causing the noteworthy declination of dependent variable. Thus we suggest that UN should balance the resources invested in these seemingly unimportant but precarious goals and

priorities.

7.1 Technology

From the World Intellectual property organization, we choose 7 quantitative indexes to measure the development level of world technology as follows:

- plant variety titles issued worldwide
- plant variety applications worldwide
- industrial design applications worldwide
- application design counts worldwide
- trademark applications worldwide
- trademark application class counts worldwide
- patent applications worldwide.

We still use $0.7 * GDP + 0.3 * HDI$ (Normalized) to measure the world's level of "peace and flourishment".

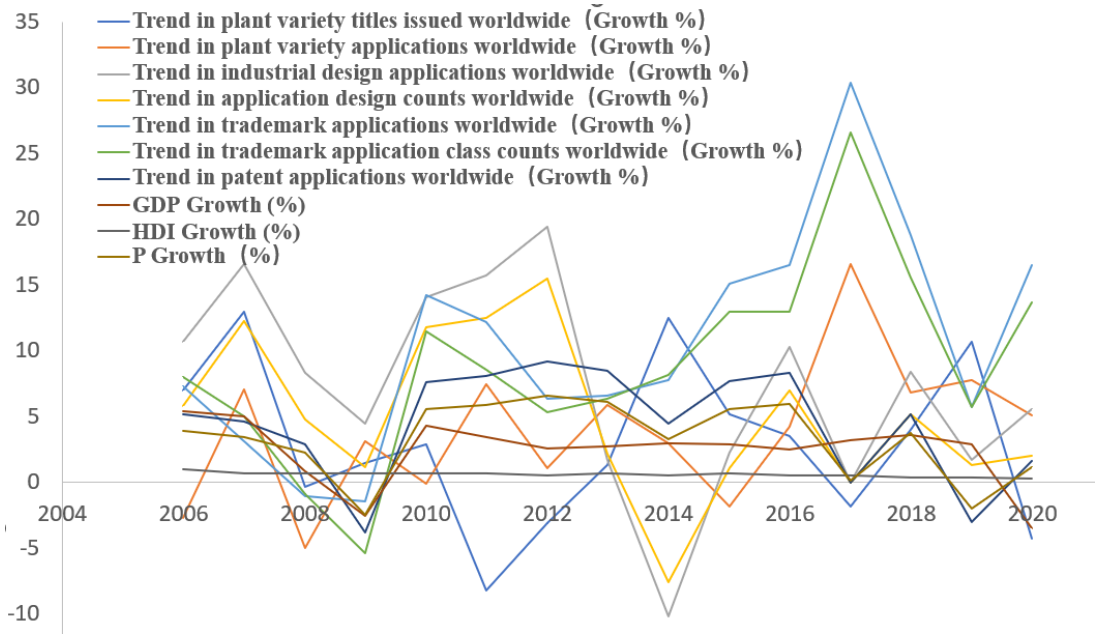


Figure 12: Data for each indicator with year

We find that there is no strong and dominant connection between technology level and our dependent variable. But obviously, there exist a close relationship between them. In year that technology grows faster, the dependent variable tends to increase faster.

Technology development has direct positive influence on goal 8 and goal 9. As our model shows, goal 8 has a close relationship with goal 10 and goal 12, so the boost of goal 8 also contributes to goal 10 and goal 12.

Goal 9 has a close relationship with goal 1,goal 2,goal 3, goal5 and goal13, its augmentation also contributes to other 5 goals' development. Conclusively speaking, technology development boost the goal 8 , goal 9 as well as the related goals, and finally results in the whole improvement of UN's goals and international peace and security, friendly relations among nations, international cooperation.

7.2 Global pandemics

Global GDP growth rates were generally relatively flat in 2019 during and prior to the COVID-19 outbreak period, while the post-outbreak period saw a significant decline in global GDP growth rates. 2020 saw the global economy hit hard by the outbreak, with many countries and regions experiencing negative economic growth rates. As for the data for 2021, economic growth rates improved in many countries and regions due to increased global vaccination rates and economic recovery plans.

Table 13: Impact of the epidemic on GDP

Year	New Case(M)	world GDP($T)	Growth(%)
2016	-	75.31	2.54
2017	-	80.08	3.23
2018	-	84.97	3.61
2019	-	88.1	2.86
2020	82.66	84.75	-3.48
2021	80.59	91.5	5.8

COVID-19 directly influences goal 2, goal 3 and goal 8 negatively.

- Goal 2 has connections with goal 3, goal 4, goal 11, goal 13, goal 15.
- Goal 3 has relatively close relationship with goal1, goal5, goal 6, goal 7.
- Goal 8 has a close relationship with goal 10 and goal 12.

So the decreasement of goal 2, goal 3, goal 8 almost negatively influence the whole society and economy.

7.3 Climate change

7.3.1 Global view

In recent years, the world has been on the brink of climate catastrophe, the consequences of which are already being felt by billions of people. 2021 energy-related emissions rise by 6 percent in 2021 to a record high, completely offsetting the decline in pandemic-related CO Based on current voluntary commitments by countries to climate action, greenhouse gas emissions will increase by nearly emissions will increase by nearly 14 percent over the next decade.

7.3.2 Focus on certain country

In November 2013, the Philippines was hit by Typhoon Haiyan, one of the strongest typhoons on record, which devastated the central Philippines.

Typhoon Haiyan reportedly killed at least 6,300 people and caused millions to lose their homes and livelihoods. The Philippine government estimates that the typhoon caused economic losses of approximately US$1.44 billion, or 1.4% of the country's GDP for the year. In addition, the typhoon caused significant damage to the Philippines' infrastructure, agriculture and fishing industries, with long-term effects on the Philippine economy.

According to the World Bank, the quarterly adjusted real gross domestic product (GDP) figures for the Philippines are as follows (in U.S. dollars)

Table 14: GDP before and after the tsunami hit the Philippines
(Unit: hundreds of millions of dollars)

Month	Sept. 2013	Oct. 2013	Nov. 2013	Dec. 2013	Jan. 2014	Feb. 2014
GDP	63.45	63.95	63.37	65.32	64.72	62.94

It is important to note that these data do not take into account the impact of Super Typhoon Haiyan on the Philippine economy, as GDP data usually takes time to collect and calculate, while Super Typhoon Haiyan occurred in early November, and the impact of the event may take longer to be truly reflected in the GDP data.

We choose the factors that more accurately reflect the impact of this extreme weather event on the Philippines: GDP growth, employment data, consumption data, and export data.

Here are the changes in these key data for the Philippines during and after Typhoon Haiyan:

1. GDP growth rate: According to the World Bank, the Philippines' GDP growth rate was 7.0% in the 3rd quarter of 2013 (after Typhoon Haiyan in November), but fell to 6.3% in the 4th quarter (after Typhoon Haiyan). In 1Q 2014, GDP growth rate was 5.6%.

2. Employment data: In November 2013, the employment rate in the Philippines was 93.4%, but fell to 92.5% in December. in January 2014, the employment rate rebounded to 93.7%.

3. Consumption Data: Consumption data in the Philippines is usually measured by retail sales and consumer confidence indices, among others. According to the Philippine Statistics Authority, retail sales in the Philippines rose 9.3% year-on-year in November 2013, but fell to 7.1% in December. The consumer confidence index also declined during the typhoon.

4. Export Data: The Philippines' main exports include electronics, apparel, food and chemicals. According to the Philippine National Statistics Office, Philippine exports grew 19.2% year-on-year in November 2013, but declined to 1.3% in December.

Climate change relates to goal 13, which connected with goal 5,goal 7,goal 11. In the area sufferred extreme climate change, we can spot considerate decline in goal 13 and according decreasement of goal 5, goal 7, goal 11.

7.4 Regional war and Refugee movements

7.4.1 Regional war

Syria has been in a fierce civil war since 2011, and its GDP has suffered greatly as a result, with its GDP rising steadily and at a high rate before that, and declining sharply after the civil war began. Since the outbreak of the Syrian civil war in 2011, millions of Syrians have fled their homes. According to the UN Refugee Agency (UNHCR), the number of Syrian refugees has exceeded 6 million.

Table 15: Syrian GDP data before and after the war
(Unit: hundreds of millions of dollars)

Year	2006	2007	2008	2009	2010	2011	2012
GDP	1538	1800	2181	2246	2525	675	432
Growth rate	14.58%	17.03%	21.17%	2.98%	12.41%	-73.25%	-35.85%
2013	2014	2015	2016	2017	2018	2019	2020
214	215	165	126	164	214	224	111
-50.46%	0.47%	-23.26%	-23.64%	30.16%	30.49%	4.67%	-50.89%

Belarus and Poland have political and economic conflicts in recent years, which led to the border war. However, due to the small scale, the economic prosperity and social development of related countries have not been significantly affected.

Table 16: GDP data for Belarus and Poland before and after the conflict

Year	Belarus GDP	Growth(%)	Poland GDP	Growth(%)
2017	1736.3	-	5246	-
2018	1833.77	5.61%	5888	12.24%
2019	1892.7	3.21%	5961	1.24%
2020	1902.11	0.50%	5994	0.55%
2021	2026.71	6.55%	6794	13.35%

Yemen's Civil War: Since 2015, a civil war has erupted in Yemen, with Houthi rebels fighting against Yemeni government forces and a coalition of United Arab Emirates forces that support them. The war has killed thousands of people and exacerbated the famine and humanitarian crisis in the region.

Table 17: GDP in Yemen before and after the war

Year	Yemen GDP (billion dollars)	Growth(%)
2014	262.4	-
2015	209.6	-20.13%
2016	182.5	-12.91%
2017	139.9	-23.37%
2018	115.8	-17.22%
2019	98.6	-14.86%

7.4.2 Refugee movements

1. Rohingya refugee crisis: Since August 2017, thousands of Rohingya Muslims have fled ethnic persecution in Myanmar for neighboring Bangladesh. The U.N. refugee agency estimates that more than 1 million Rohingya refugees are already in Bangladesh.

2. Syrian refugee crisis: Millions of Syrians have fled their homeland since the country's civil war broke out in 2011. The number of Syrian refugees has passed six million, according to the United Nations refugee agency (UNHCR).

3. Libya's refugee crisis: Since civil war broke out in Libya in 2011, the country has become a transit point for millions of refugees and migrants. The U.N. refugee agency estimates that about 450,000 people are waiting to be relocated or resettled in or around Libya.

Typically, regional wars concurrent with refugee movements. They directly lead to a steep decline in almost every goal, thus we should put high attention and resources to avoid regional wars.

This related to (SDGs) respectively, although their importance in the model is not high, once affected, they will have a large decline, thus significantly affecting the dependent variables, so we should strengthen the guard against these factors.

7.5 Impact on priorities:

Things like regional wars or extreme climate change are not frequent and thus the society do not attach enough importance and attention to them. However, once the extreme event happens, it will lead to a steep and large scale influence on the whole society. Consequently, we should balance the resource to prevent extreme events and develop the goals.

8 TASK 5: Model extension

Our approach to prioritizing goals can also be applied to other companies or organizations to help them prioritize their goals. The specific model is as follows:

1. Clarify the ultimate expectation and goal to be achieved, and split them into relatively small, implementable and quantifiable goals.
2. Collect data on the feasibility and profits of each goal from credible data sources.
3. Clarify the relationship between the small goals through literature and logic judgment, combine the feasibility and profits of the small goals themselves and the cost of implementation, generate the final effectiveness in the network, and determine the priority of achieving the goals.
4. Because there are more unstable perturbations in the real world, it is necessary to prevent the risks brought by unstable factors outside the model, and trade off the resources invested into the priorities with the risk-resistant assets.

9 Strengths and Weaknesses

9.1 Strengths

- Since the SDGs aims at the peace and prosperity among humans, we choose weighted global GDP and HDI as our dependent variable to establish the model. and balance the result of random forest regression and adaboost regression,succefully determined the weights of eachgoals.
- Collected the data of each sub-indicator under the 17 goals, determined the weights of each sub-indicator by hierarchical analysis, and calculated the quantitative indicators of the 17 SDGs in each year.

- Judged the influence of each goal by linear dependency, combined with the weight of each goal in the model, and calculated the final impact of the actual change of each indicator on the dependent variable.
- Rigorous quantitative analysis using data from reliable sources to support the inference.

9.2 Weaknesses

- 17 SDGs can not describe all aspects of the society and merely use global GDP and HDI can not perfectly match 17 SDGs, hence there are acceptable and Inevitable deviations in the model.
- There are not many years with complete data for each sub-indicator of the 17 SDGs, resulting in an insufficient amount of data for training the model.

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