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2015 Mathematical Contest in Modeling (MCM) Summary Sheet

(Attach a copy of this page to each copy of your solution paper.)

Abstract

In order to achieve a more sustainable future, we propose a method to measure the sustainability of a country and create a sustainable development plan for Haiti. Our indicator framework takes account of 14 factors and three themes including society, economy and ecology.

Firstly, Grey Comprehensive Evaluation (GCE) as a basic model, is established to measure the sustainability of a country. After that, our advanced slack-based Data Envelopment Analysis (**slack-based DEA**) model helps measure economic, social and ecological sustainable development effeciencies. Based on these two models, we calculate 178 countries' sustainability scores and classify them into four levels range from I to IV. As a result, we conclude that these countries in low sustainable level need the most support.

To apply our measure models, we select Haiti from the 48 Least Developed Countries (LDC) list and create a 20 year sustainable development plan for it. During the process, we obtain goals of our plan based on **output slacks** from DEA model. Thus, many specific strategies that can be carried out by the International Conglomerate of Money (ICM) are mapped out.

Furthermore, we evaluate the effect of our plan on Haiti's sustainability measure. During the process, we predict the changing values of three parts in Haiti: the indicators, Haiti's sustainability score (based on GCE model) and Haiti's sustainable development efficiencies of ecology, economy and society (based on slack-based DEA model). Besides, we take **additional environmental factors** into account, Haiti earthquake for example. Finally, we determine which strategies produce the greatest effect via Grey Correlation Analysis (**GCA**).

Keywords: Sustainability Grey Comprehensive Evaluation Slack-based DEA Plan Grey Correlation Analysis

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1 Introduction

Problem Background

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (Gro Harlem Brundtland, the Brundtland Report 1987)

Access to a sustainable world becomes an ever more critical concern for humanity beings in the 21st century. In fact, humanity is already in overshoot in terms of using more resources than Earth can renew. How can we manage increasing population and consumption with the earth's finite resources? Sustainable development must focus on needs (e.g., reducing the vulnerability of the world's poor) and limitations (e.g., the environment's ability to detoxify wastes). In summary, this sustainable challenge is not only an inconvenient truth, but rather a critical issue that demands bold action of human beings from all over the world.

Previous Research

Since the creation of the United Nations, people from all over the world have aspired to make progress on the great global issues of sustainable development. After the Brundtland Report, concept of sustainable development was subsequently adopted by Governments at the Earth Summit of 1992 in Rio de Janeiro and a global action plan, which included many goals and targets [9]. After that, SD21 study was held by the UN Division for Sustainable Development [2]. Thus, the study on sustainable development has become ever-more meaningful, incorporating many science and policy elements. In 2012, the UN Conference on Sustainable Development (Rio+20) was held in Rio de Janeiro to mark the 20th anniversary of the historic Rio Earth Summit. More importantly, Rio+20 is also call for a global sustainable development report. Therefore, we write this report to express our fervent hope for a more sustainable world.

Our Work

In order to achieve a more sustainable world, we develop two models to help measure the sustainability of a country. Then we apply our models to 178 countries and create a 20 year sustainable development plan for one of them. In addition, effect of our plan on this country is evaluated and those highly effective strategies that could be implemented by ICM are all illuminated. Through our work, the following questions have been discussed:

- Define our own indicator framework based on previous studies.
- Develop two models for the sustainability of a country and define when and how a county is sustainable or unsustainable.
- Inform the ICM on those countries that need the most support and intervention.
- Apply our models to 178 countries and create a 20 year sustainable development plan for one of them.
- Evaluate the effect our 20-year sustainability plan has on the country's sustainability measure.
- Predict the change that will occur over the 20 years in the future consider additional environmental factors.
- Identify highly effective programs or policies that could be implemented by ICM.

2 Assumptions

- Assume that the dataset of each indicators is reliable.
- Assume that indicators in our framework are sufficient enough to reflect the sustainability of a country.
- Assume that there is no additional factor that can influence the measure of sustainability.

3 Symbols and Definitions

Table 1: Symbols and Definitions

I_k	The indicator for k^{th} in the indicator framework
A	The original data matrix in grey comprehensive evaluation model
ξ	The associate coefficient in grey comprehensive evaluation model
E	The associate coefficient matrix in grey comprehensive evaluation model
w_i	The weight of i^{th} indicator in grey comprehensive evaluation model
S_i	The comprehensive score of i^{th} indicator in greg comprehensive evaluation model
X	The input of indicator in Slack-Based DEA model
Y	The output of indicator in Slack-Based DEA model
ρ	The efficiency in Slack-Based DEA model

4 Defining Indicator Sets

Many indicator frameworks serve to help us clarify what kinds of indictors to use and what to expect from measurement. Furthermore, most approaches for sustainability assessment today are, in broad terms, based on pressure-state-response frameworks, theme-based frameworks, or aggregate indicators such as Sustainable Progress Index (SPI) [7]. On the one hand, based on the detailed analysis of those frameworks, pressure-state-response frameworks fail to account for system relationships and dynamics [5]. Likewise, aggregate indicators have many limitations, for example, Ecological Footprint as an excellent summary indicator of the major environmental impacts of economic activity, cannot capture the social dimensions of sustainable development [11]. On the other hand, the selection of frameworks is based on its use case, whether it comes to policy targets, public awareness or environmental issue. Considering that the International Conglomerate of Money (ICM) hire us to help make policies and aid scenarios, therefore, our models in this report are based on a thematic framework. In the next paragraph, we will explain our models' three specific themes and 14 indicators.

The UN Commission for Sustainable Development indicators (current CSD indicators) contain 14 themes (shown in Fig. 1) and a core set of 50 indicators [1]. Since current CSD indicators are a set of well-defined and widely-used indicators, our models take these indicators into account. However, due to a lack of relevant data, we attempts to reduce these 50 indicators to 14 ones and use the limited real-world data available to explain our models. In other word, all the CSD indicators can be used when datasets are complete.

CSD indicator themes

- Poverty
- Governance
- Health
- Education
- Demographics

- Natural hazards
- Atmosphere
- Land
- Oceans, seas and coasts
- Freshwater
- Biodiversity

- Economic development
- Global economic partnership
- Consumption and production patterns

Figure 1: UN CSD sustainable development indicators [1]

Particularly, those 14 indicators derived from CSD indicators are based on a thematic framework which consist of three themes economy, ecology and society (shown in Fig. 2). And the determination of these three themes are explained as follows. Sustainability can be defined as a dynamic balance among three mutually interdependent elements: protection and enhancement of natural ecosystems and resources; economic productivity; and provision of social infrastructure such as jobs, housing, education, medical care and cultural opportunities [6]. According to this definition by Dominski et al, we consider measure the sustainability of a country in accordance with three parts: economy, ecology and society.

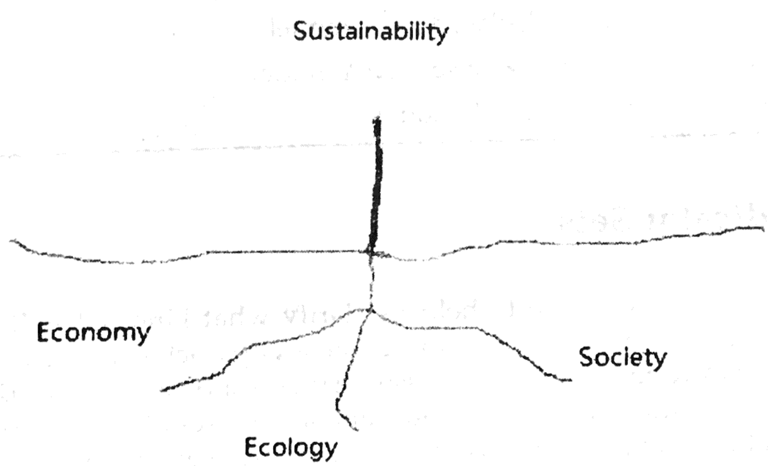

Figure 2: Economy, Ecology and Society

Through above analysis of indicators, all the themes and indicators in our models are shown in Fig. 3.

Society	Poverty	Improved sanitation facilities(% of population with access) (ISF)
		Improved water source(% of population with access) (IWS)
		Access to electricity(% of population) (AE)
	Health	Life expectancy at birth (LEB)
	Demographics	Population growth (PG)
Ecology	Atmosphere	CO2 emissions(metric tons per capita) (CO2)
	Land	Arable land(% of land area) (AL)
		Forest area(% of land area) (FA)
	Oceans, seas and coasts	Terrestrial and marine protected areas (% of total territorial area) (TMPA)
	Freshwater	Renewable internal freshwater resources per capita (RIFR)
	Biodiversity	GEF benefits index for biodiversity (GEF)
	Economic Development	GDP per capita (GDP)
Economy	Consumption and production patterns	Final consumption expenditure, etc. (% of GDP) (FCE)
		Energy use (kg of oil equivalent per capita) (EU)

Figure 3: Our Indicators

5 Two Models: To Evaluate the Sustainability

Our indicators for sustainability measure is based on three themes: society, economy, ecology. However, when society, economy and ecology are viewed as separate, unrelated parts of a country, the problems in this country are also viewed as isolated issues. In this way, the measures might have some unexpected side-effects. For example, solutions to one problem can make another problem worse. Building affordable housing is a good thing, but when housing is built, the result is more pollution and increasing traffic that comes with it. Hence, sustainable development is about understanding the connections between and achieving balance among the economic, social and ecological pieces of a country.

Based on the analysis above, we select Grey Comprehensive Evaluation (GCE) Model to measure sustainability of a country [12]. Grey Comprehensive Evaluation method is a kind of factor comparative approach, in which the relationship among each factor in the system is to be sought so as to find out the main element affecting the target value and to study the correlation degree between the factors by setting up the reference sequence and the comparative one and analyzing the limited data sequence in the grey system.

5.1 Basic Model: Grey Comprehensive Evaluation Model

5.1.1 Establish Grey Correlation Model

In this model, let m denotes the number of participating countries, where $m > 1$ and let n denotes the number of indicators, where $n > 1$.

Step1: Obtain original data matrix

Based on indicators data of each country, we obtain original data vector

$$A_i = (a_i(1), a_i(2), \cdots, a_i(n)),$$

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where i denotes the i^{th} country and $a_i(j)$ denotes the $a(j)$ value for the i^{th} country. Through putting together all indicators data of each country, we obtain original data matrix

$$A = \begin{bmatrix} a_1(1) & a_1(2) & \cdots & a_1(n) \\ a_2(1) & a_2(2) & \cdots & a_2(n) \\ \vdots & \vdots & \vdots & \vdots \\ a_m(1) & a_m(2) & \cdots & a_m(n) \end{bmatrix}.$$

Step2: Data standardization

The difference of n indicators will lead to an inconvenient comparison, so it is necessary to standardize all the indicator data in grey correlation analysis. As for positive and negative indicators respectively, we standardize data in different ways.

Positive indicators:

$$p_i(j) = \frac{a_i(j) - \min\limits_i a_i(j)}{\max\limits_i a_i(j) - \min\limits_i a_i(j)}, i \in \{1, 2, \cdots, m\}, j \in \{1, 2, \cdots n\},$$

Negative indicators:

$$p_i(j) = \frac{\max\limits_i a_i(j) - a_i(j)}{\max\limits_i a_i(j) - \min\limits_i a_i(j)}, i \in \{1, 2, \cdots, m\}, j \in \{1, 2, \cdots n\},$$

where $\min\limits_i a_i(j)$ denotes minimum value of the j^{th} indicator, $\max\limits_i a_i(j)$ denotes maximum value of the j^{th} indicator.

Then, we can obtain the standardized matrix

$$P = \begin{bmatrix} p_1(1) & p_1(2) & \cdots & p_1(n) \\ p_2(1) & p_2(2) & \cdots & p_2(n) \\ \vdots & \vdots & \vdots & \vdots \\ p_m(1) & p_m(2) & \cdots & p_m(n) \end{bmatrix}.$$

Step3: Define reference data series

In grey correlation analysis, reference data series serve as ideal comparison indicators, which yield optimal results. If we expect larger value of indicator to yield better results, then the maximum value of all indicators is selected as reference data. In contrast, the minimum value is selected as reference data. Thus, reference data series P_0 are defined as

$$P_0 = (p_0(1), p_0(2), \cdots p_0(n)).$$

Step4: Calculate correlation coefficient

We can calculate correlation coefficient $\xi_{0i}(j)$ by the equation

$$\xi_{0i}(j) = \frac{\Delta_{\min} + \rho\Delta_{\max}}{\Delta_{0i}(j) + \rho\Delta_{\max}}, i \in \{1, 2, \cdots, m\}, j \in \{1, 2, \cdots, n\},$$

where $\Delta_{0i}(j)$ denotes the absolute difference of j^{th} indicator between comparison indicator series P_i and reference data series P_0, and can be calculated by the equation

$$\Delta_{0i}(j) = |p_0(j) - p_i(j)|.$$

Let $\Delta_{\min}$ denote the minimum value of all the $\Delta_{0i}(j)$ value, namely

$$\Delta_{\min} = \min_j \min_i \Delta_{0i}(j).$$

Let $\Delta_{\max}$ denote the maximum value of all the $\Delta_{0i}(j)$ value, namely

$$\Delta_{\max} = \max_j \max_i \Delta_{0i}(j).$$

Let ρ denote resolution ratio, and $0 \le \rho \le 1$. Where, we select $\rho = 0.5$.

Step5: Obtain correlation coefficient matrix

After calculation all the correlation coefficients, we obtain correlation coefficient matrix

$$E = (\xi_{0i}(j))_{m\times n} = \begin{bmatrix} \xi_{01}(1) & \xi_{01}(2) & \cdots & \xi_{01}(n) \\ \xi_{02}(1) & \xi_{02}(2) & \cdots & \xi_{02}(n) \\ \vdots & \vdots & \vdots & \vdots \\ \xi_{0m}(1) & \xi_{0m}(2) & \cdots & \xi_{0m}(n) \end{bmatrix}.$$

Step6: Calculate average value of correlation coefficient

In order to quantify the relationship between each country and reference data series, we can calculate average value of correlation coefficient in accordance with each country and reference data series by the equation as

$$r_j = \frac{1}{m}\sum_{i=1}^{m} \xi_{0i}(j).$$

Step7: Calculate the weight of each indicator

After calculating the r value of each indicator, we can calculate the weight of each indicator by the equation

$$w_i = \frac{r_i}{r_1 + r_2 + \cdots + r_n}, i \in \{1, 2, \cdots, n\}.$$

Step8: Calculate sustainability score of each country

Finally, we can determine general measure method by calculating each country's sustainability score

$$S_i = w_1 p_i(1) + w_2 p_i(2) + \cdots + w_n p_i(n), i \in \{1, 2, \cdots, n\}.$$

With the purpose of distinguishing more sustainable countries and policies from less sustainable ones, we classify all countries into four sustainability levels range from I to IV (shown in Tab.2). Then how does this sustainability appraisal model work? By calculating sustainability score. That is to say, if the sustainability score of a country is high enough to be classified into a high level, this country will be regarded as more sustainable in comparison to other low-level countries.

Table 2: The Four Sustainability Level

Level	S	Sustainability
I	> 0.7	High
II	$0.6 - 0.7$	Medium
III	$0.5 - 0.6$	Low
IV	< 0.5	Least

5.1.2 Results and Analysis

Based on grey comprehensive evaluation model explained above, we can calculate sustainability scores of these 178 countries. And a rank of all participating countries along with corresponding sustainability scores are shown in the Tab.3.

Table 3: Results of Grey Comprehensive Evaluation Model

Rank	Country	Scores
1	Sweden	0.743784
2	New Zealand	0.742812
3	Switzerland	0.740746
4	Finland	0.739984
5	Slovenia	0.739837
...	...	...
174	Sierra Leone	0.442369
175	Malawi	0.441359
176	Haiti	0.435694
177	Togo	0.427927
178	Chad	0.426724

The table 3 shows both the top five and the last five ranking countries based on sustainability scores. As for these top five countries including Sweden, New Zealand, Switzerland, Finland and Slovenia, they are regarded as sustainable countries by most people. What's more, when it comes to the last 10 countries such as Chad, Togo and Haiti, we surprisingly find that these last 10 countries are all in the Least Developed Countries (LDC) list [3]. Thus in the next section, we will further discuss the relationship between sustainability and development degree of a country.

5.2 Advanced Model: Slack-Based DEA Model

Data Envelopment Analysis (DEA) is a non-parametric technique which is usually employed to measure the relative efficiency of decision making units (DMUs) in utilizing inputs to produce outputs [8]. In this section, we utilize Data Envelopment Analysis to measure the countries' efficiency in utilizing resources to promote social, economic and ecological sustainability developments. In addition, the efficiency score from the slack-based DEA indicates the amount of inputs which country needs to reduce and the amount of outputs which country needs to produce so that it can be considered efficient. Therefore, this model also provide a basis for the 20 year sustainable development plan in the next section.

5.2.1 Establish DEA Model

In this section, definitions of both the slack-based measure of efficiency and the reference-set will be given, along with its interpretation as a country of input (resource) and output (sustainable development) inefficiencies.

Definition 1: SBM-efficient

A DMU(x_0,y_0) is SBM-efficient if $\rho = 1$. In other word, a DMU(x_0,y_0) is SBM-efficient on condition that $s^- = 0$ and $s^+ = 0$, i.e., no input excesses and no output shortfalls in any optimal sustainability of a country.

Definition 2: Reference-set

The reference-set is defined as

$$R_o = \{j|\lambda_j > 0\}(j \in \{1, 2, \cdots, n\}).$$

We assume that n decision-making units (countries) are with same input matrix $X = (x_{ij}) \in \mathbb{R}^{m\times n}$ and outputs matrix $Y = (y_{ij}) \in \mathbb{R}^{m\times n}$. And assume that all the inputs and outputs are positive, i.e. $X > 0$ and $Y > 0$. And the method of estimating sustainable development efficiency of country is expressed in the following four steps.

Step1: Define the production possibility set of sustainable development

Based on the reference-set (expressed in Definition 2), we can define the production possibility set of sustainable development as follows

$$P = \{(x_i, y_i)|x_i \geqslant \sum_{j=1}^{n} \lambda_i x_{ij}, y_r \leqslant \sum_{j=1}^{n} \lambda_i y_{rj}, \lambda \geqslant 0, i = 1, 2, \cdots, m, r = 1, 2, \cdots, s\}.$$

Step2: Calculate the amount of input and output of each country

DMU(x_{i0},y_{r0}) represents a country. And x_{i0} denotes the amount of i^{th} resource, y_{r0} denotes the amount of j^{th} aspect of sustainable development. Then, x_{i0} and y_{r0} can be calculated by the equation

$$x_{i0} = \sum_{j=1}^{n} \lambda_j x_{ij} + s_{i0}^{-},$$

$$y_{r0} = \sum_{j=1}^{n} \lambda_j y_{rj} - s_{r0}^{+},$$

where $\lambda \geqslant 0$, $s^- \geqslant 0$, $s^+ \geqslant 0$. And, s^- denotes input slacks, which reflects the input excess. s^+ denotes output slacks, which reflects the output shortfall.

Step3: Calculate the efficiency score of sustainable development

Using the value of s^- and s^+, we can calculate the efficiency score by the equation

$$\rho = \frac{1 - (1/m)\sum_{i=1}^{m} s_i^- / x_{i0}}{1 + (1/s)\sum_{r=1}^{s} s_r^+ / y_{r0}},$$

where $0 < \rho \leqslant 1$.

Step4: Optimal the efficiency score

In order to estimate the sustainable development efficiency of each country, we formulate the fractional program as follows,

$$\min \rho = \frac{1 - (1/m)\sum_{i=1}^{m} s_i^- / x_{i0}}{1 + (1/s)\sum_{r=1}^{s} s_r^+ / y_{r0}},$$

$$s.t. \begin{cases} x_{i0} = \sum_{j=1}^{n} \lambda_j x_{ij} + s_{i0}^{-}, i = 1, 2, \cdots, m \\ y_{r0} = \sum_{j=1}^{n} \lambda_j y_{rj} - s_{r0}^{+}, r = 1, 2, \cdots, s \\ \lambda_j \geqslant 0, s_{i0}^{-} \geqslant 0, s_{r0}^{+} \geqslant 0, j = 1, 2, \cdots, n \end{cases}$$

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The efficiency score ρ will equal to 1 if all input slacks equal to 0. And let x_{ij} denotes the amount of i^{th} input of j^{th} country, y_{ij} denote the amount of i^{th} input of j^{th} country.

5.2.2 Results and Analysis

In this model, based on our thematic framework which consist of three themes - economy, ecology and society, we utilize the slack-based DEA method to analysis the efficiency of every countries' economic sustainability development, ecological sustainability development and social sustainability development, respectively. Table 4 shows social (one of these three themes) sustainability development efficiency of five countries including Sweden, Slovenia, Haiti, Togo and Chad.

Table 4: The Results of Efficiency

	Total Efficiency	Technology Efficiency	Scale Efficiency
Sweden	0.873	1	0.873
Slovenia	0.864	1	0.864
...	...	...	...
Haiti	0.644	0.912	0.706
Togo	0.657	0.942	0.697
Chad	0.645	0.937	0.688

Table 5: The Slack Value of Social Indicators

	ATE	ISF	IWS	LEB
Sweden	0	0	0	0.879
Slovenia	0	0	0	0.883
Haiti	16.07	35.263	13.545	5.969
Togo	20.31	27.612	18.216	2.341
Chad	21.87	29.215	15.387	3.212
	PG	CO2	EU	FCE
Sweden	0.031	-0.052	-2043.89	-4.479
Slovenia	0.021	-0.14	-133.341	-4.168
Haiti	0.322	0	0	-9.243
Togo	0.214	0	0	0
Chad	0.205	0	0	-7.211

From the Table 4 and Table 5, the results of slack-based DEA is consistent with grey comprehensive evaluation method. For example, Sweden keeps the top rank in both DEA and GCE models. Also, we find total efficiency is made up of technical efficiency and scale efficiency. These values of input and output slacks reflect the excess of sources consumption and the shortfall of sustainable development and thus, they can serve to help make policies for improving society sustainability development efficiency. To further discussion, we will take account of all the results to create sustainable development plans for specific countries.

5.3 Model Conclusion

In this work, we propose two models to help measure the sustainability of a country. The GCE model is utilized to measure whether a country is more sustainable or not. And 14 factors are taken into consideration such as access to electricity, life expectancy at birth, improved water sources, etc. In addition, we come to the conclusion that it is these countries in the lowest level (explained in Tab.2) that indeed need the most support and intervention from ICM. In our basic model, with an overall view we utilize grey comprehensive evaluation model to calculate each country's sustainability score. Based on these scores, a ranking of sustainability is presented and all participating countries can be classified into 4 levels. Therefore, by calculating sustainability scores, our first model provides a measure to distinguish more sustainable countries from less sustainable ones. In our advanced model, we present slack-based Data Envelopment Analysis to measure the countries' efficiency in utilizing resources to promote social, economic and ecological sustainability developments.

6 Model application: Our 20 Year Sustainable Development Plan for Haiti

Haiti is a country on the Caribbean island of Hispaniola and its capital city is Port-au-Prince [4]. Besides, Haiti is the only country in the Americas on the United Nations list of Least Developed Countries and it is the poorest country in the Americas. It is also one of the least developed and poorest countries in the world. About 90% of the Haitian people were living in poverty in 2003. The economy staying even or falling behind even before their big earthquake (2010). And the country used to be covered with forests. However, it no longer is, because of deforestation. Based on this situation, we select Haiti from the United Nations list of the 48 Least Developed Countries so as to create a 20 year sustainable development plan which can help them move towards a more sustainable future.

6.1 Sustainability analysis of Haiti

In order to measure the sustainability of Haiti, we apply the two models explained in Section 5 into our plan making. According to the results of grey comprehensive evaluation (GCE) model, on the one hand, we obtain the sustainability score of Haiti as well as two extra scores including technical and scale scores. On the other hand, the sustainability level of Haiti is also defined. As is shown in Tab.3, Haiti ranks rather low and because of the low score, Haiti is classified into the lowest level, which reflect that Haiti is less sustainable in comparison to other countries and needs some support and aids from ICM. What's more, in Section 5 we only provide the results of society sustainability development. When it comes to analyzing the situation of Haiti only, we shows detailed results based on society, economy and ecology as follows.

Table 6: The Efficiency Results of Three Aspects

Efficiency	Total Efficiency	Rank	Technical Efficiency	Rank	Scale Efficiency	Rank
Society	0.644	129	0.912	176	0.706	98
Economy	0.798	144	0.806	131	0.99	138
Ecology	0.687	84	0.784	74	0.875	147

From an overall perspective, efficiency scores (including total, technical and scale efficiency) reflect the sustainability of Haiti along with techinical sustainability and scale sustainability. In addition, slack-based DEA indicates the amount of outputs which Haiti needs to produce so that it can be considered efficient. Thus, it is critical to point out that values of output slacks are very important when one attempts to put sustainability into practice. Therefore, based on the output slacks, we can provide a 20 year sustainable development plan in the next paragraphs.

6.2 Our Plan

6.2.1 Strategies for Society

Table 7 shows the goals of social sustainability efficiency in Haiti, namely, the expected amount of outputs Haiti needs to produce so that it can be considered efficient. For example, Haiti should increase the value of access to electricity (AE) by 16.07%, in other words, Haiti should take measures to build more power equipment. Then, in the next paragraph, many plans aimed at these goals (including programs, policies, and aid) are proposed.

Table 7: Society Goals

	Indicators	Original Value	Slack Value	Project Value
Society	AE	33.9	16.07	49.97
	ISF	24.6	35.263	59.863
	IWS	62.4	13.545	75.945
	LEB	62.89	5.969	68.859
	PG	1.402	0.322	1.724

- Construct nation traffic and enhance national highway coverage to help build up the whole society. ICM are supposed to offer financial assistance and talent support during the process.
- Develop multifunctional electric power plant to satisfy the requirement of the society. ICM ought to provide financial and technical support in site selection and nuclear electrical power plant construction. Construct the water supplying system and increase the utilization efficiency of water to grow in the number of per capita water consumption to ensure people's life.
- Advance the level of national medical treatment and build the national medical system. During the process, ICM need to provide numerous medical technical personnel and medical infrastructure assistance.

6.2.2 Strategies for Economy

Table 8 reflects the goals of economic sustainability efficiency in Haiti. The situation is the same as social sustainability efficiency. Likewise, many plans aimed at these goals (including programs, policies, and aid) are proposed as follows.

Table 8: Economy Goals

	Indicators	Original Value	Slack Value	Project Value
Economy	GDP	819.904	427.239	1247.143
	FCE	104.616	-7.249	97.367

- Stimulate the commodity market, develop the country commodity economy and expand the export. The government can raise appropriate tariff for the import and actively develop small and medium sized enterprises to create more jobs and increase employment rate. With the fundamental assistance of ICM, government of Haiti can make good use of the natural resources and promote the industries in relation to tourism.

- Give guidance to the national consumption legitimately then create a rich market to provide the nation more opportunities to consume.
- Adjust the structure of the economy, together with actively importing talented person majoring in economy. This can be done by assistance of the volunteer project of ICM and those talented persons perform well in making economy policies.
- Attract foreign investment and economy support. ICM can provide direct these support directly or call on more enterprises to invest.

6.2.3 Strategies for Ecology

Table 9 shows the goals of ecological sustainability efficiency in Haiti. Likewise, many plans aimed at these goals (including programs, policies, and aid) are proposed as follows.

Table 9: Ecology Goals

	Indicators	Original Value	Slack Value	Project Value
Ecology	AL	36.284	9.969	46.253
	CO2	0.2678	0.082	0.3498
	EU	325.213	343.6	668.813
	FA	3.578	15.443	19.021
	RIFR	1260.969	2128.893	3389.862
	GEF	5.167	14.6385	19.806
	TMPA	0.1	2.31	2.41

- Raise the rate of national forest coverage as well as the area. ICM can provide financial support upon this.
- Build the scientific utilization system of biological resources to increase the efficiency of utilization rate. What ICM can do is to offer related techniques.
- Enhance the biological diversities, forbid killing the wild animals and protect the ocean biological environment. ICM can give guidance to this protection.
- With the development of industry and economy, government will set up biological protection districts. ICM need to call on international wild animal protection organizations to take part in and build the biological environment together.

7 The Effects of Our Plans

7.1 Assumptions

- Assume that Haiti's government implement our plan completely from 2013 to 2033 year and ICM offers enough support for Haiti to realize our goals.
- Assume that the sustainability of Haiti develops at a linear-growth speed.
- Assume that Haiti's government starts to implement our plan from year 2013.

7.2 Establish Effect Prediction Model

According to the goals of our plan (expressed in Chapter 5.1) and the above assumptions, we can predict the changing values of i^{th} indicators over time and here is the equation,

$$I_k(t) = I_k(2013) + \frac{\Delta_{I_k}}{20}(t-2013), t \in \{2014, 2015, \cdots, 2033\}.$$

Let $I_k(t)$ denotes the value of k^{th} indicator in t^{th} year, and let Δ_{I_k} denote the expected change value of k^{th} indicator from 2013 to 2033. The value of Δ_{I_k} is obtained from our plan's goals.

Through above equation, we can predict the changing process of each indicators from 2013 and 2033. Then, we apply these continuously chancing indicators (out of prediction) into our grey comprehensive evaluation model and slack-based EDA model. Finally, the change that will occur over the 20 years by implementing our plan can be predicted in our two models. And the results are shown in Tab.10.

Table 10: The Prediction Values of Indicators

	Indicators	2013	2017	2021	2025	2029	2033
Society	AE(I_1)	33.9	37.114	40.328	43.542	46.756	49.97
	ISF(I_2)	24.6	31.6526	38.7052	45.7578	52.8104	59.863
	IWS(I_3)	62.4	65.109	67.818	70.527	73.236	75.945
	LEB(I_4)	62.8902	64.084	65.2778	66.4716	67.6654	68.8592
Economy	PG(I_5)	1.4024	1.4668	1.5312	1.5956	1.66	1.7244
	GDP(I_6)	819.91	905.35	990.80	1076.24	1161.69	1247.14
	FCE(I_7)	104.61	103.17	101.72	100.27	98.82	97.37
	AL(I_8)	36.2845	38.2783	40.2721	42.2659	44.2598	46.2535
Ecology	CO2(I_9)	0.2678	0.2842	0.3006	0.3171	0.3334	0.3498
	EU(I_{10})	325.213	393.933	462.653	531.373	600.093	668.813
	FA(I_{11})	3.5782	6.6668	9.7554	12.844	15.9326	19.0212
	RIFR(I_{12})	1260.97	1686.75	2112.53	2538.31	2964.08	3389.86
	GEF(I_{13})	5.1672	8.0949	11.022	13.9503	16.878	19.8057
	TMPA(I_{14})	0.1	0.562	1.024	1.486	1.948	2.41

7.3 Results of Prediction and Effect of Plan

Based on the growth rate of each indicator (shown in Tab.10), we can measure the sustainability of Haiti in the future via GCE model. And the sustainability scores of Haiti from 2013 to 2033 are shown in Tab. 11. Based on above results, we find the sustainability scores of Haiti are increasing steadily from 2013 to 2033.

Table 11: The Sustainability Scores of Haiti From 2013 to 2033

Year	2013	2017	2021	2025	2029	2033
The Sustainability Scores	0.435694	0.456302	0.476911	0.49752	0.518128	0.538737

To further illustrate, we utilize slack-based EDA model to measure sustainable development efficiencies of ecology, economy and society in Haiti from 2013 to 2033. And the results are shown in Tab. 12. From the Tab. 12, we find sustainable development efficiencies of ecology, economy and society all maintain a steadily growth from 2013 to 2033.

Table 12: The Total Efficiency of Three Aspects from 2013 to 2033

	2013	2017	2021	2025	2029	2033
Ecology Efficiency	0.687	0.743	0.787	0.821	0.871	0.913
Economy Efficiency	0.798	0.845	0.886	0.903	0.929	0.964
Society Efficiency	0.644	0.652	0.671	0.687	0.708	0.735

7.4 Identify the Most Effective Plan

7.4.1 Considering additional environmental factors

Haiti was hit by great earthquake in 2010 and the earthquake caused major damage in all over the country. Notable landmark buildings were significantly damaged or destroyed. Based on data of year 2003 to 2013, we can predict the influence of earthquake on the sustainability of Haiti via GCE model. And the results are shown in Fig. 4.

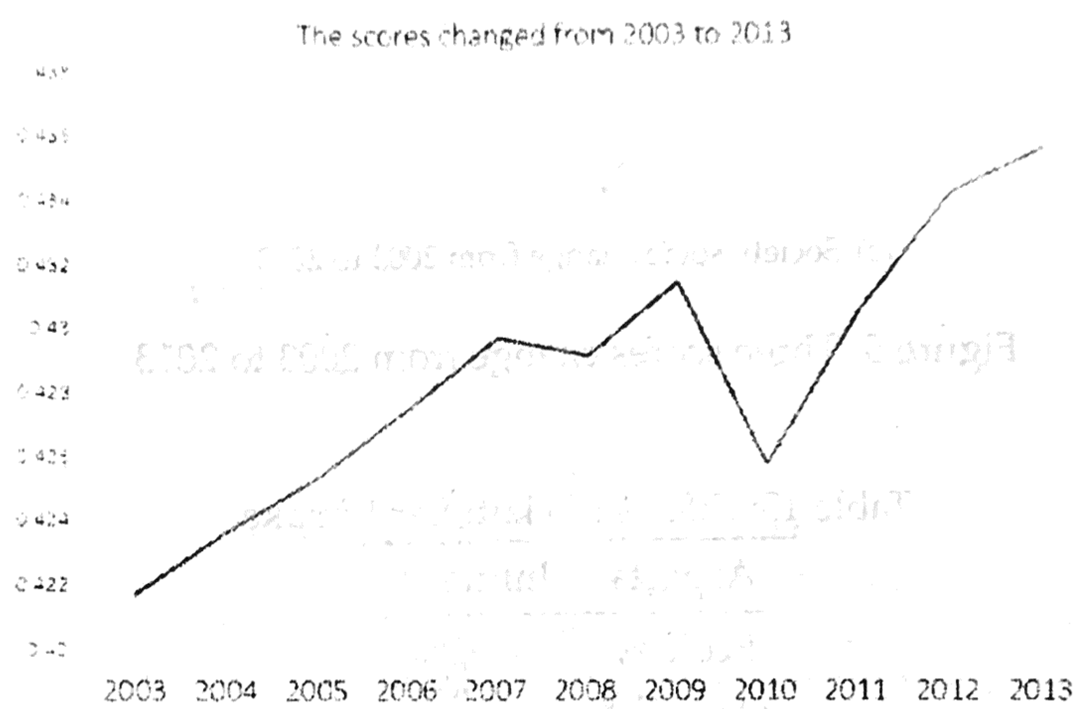


Figure 4: The scores changed from 2003 to 2013

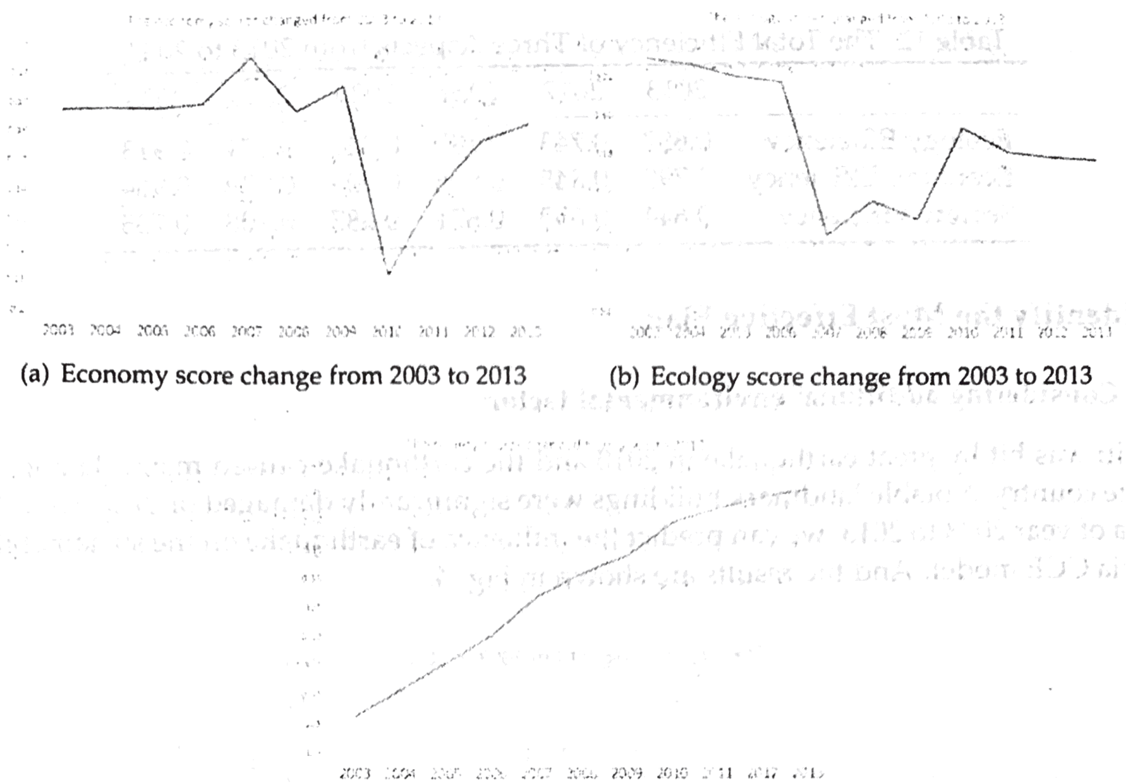
Figure 4 depicts the trend of sustainability score of Haiti. As we can see, there is a huge drop in 2010, thus proves that Haiti earthquake (2010) indeed have a significant effect on sustainability of Haiti. In addition, we utilize GCE model to further predict the effect of earthquake on ecology, economy and society. And the ecological, economic and social sustainability scores are shown in the following table respectively.

Figure 5(a) depicts the trend of economic sustainability score and shows a greatest drop in 2010 year. This indicates economy suffers the most from the earthquake in comparison to social and ecological sustainability.

Figure 5(b) shows the trend of ecological sustainability score. Unlike Figure 5(a), there is an obvious rise in 2010. The cause is that the earthquake hinder whole process of development, factory building for example, leading to an environmental improvement.

Figure 5(c) pictures the trend of social sustainability score. The sustainability score maintains a steady growth from 2003 to 2013 and this reflects society suffers little from Haiti earthquake.

Through these prediction data, we can predict the effects of Haiti earthquake on ecology, economy and society. And table 13 shows the change values of efficiency.



(a) Economy score change from 2003 to 2013 (b) Ecology score change from 2003 to 2013

(c) Society socre change from 2003 to 2013

Figure 5: Three scores change from 2003 to 2013

Table 13: Effects of Haiti Earthquake

Aspects	Influence
Ecology	0.92%
Economy	-36.22%
Society	0.85%

Table 13 indicates that economy suffers the most in comparison to social and ecological sustainability. At the same time, we can obtain the change values of the economic efficiency's two indicators (shown in Tab. 14).

Table 14: The Change Value of the two economic indicators

Indicators	Influence
Final consumption expenditure	24.78%
GDP per capita	-10.11%

7.4.2 Use Grey Correlation Analysis Model to Evaluate the Most Effective Plan

In order to evaluate the effect our strategies have on the sustainability of a country, we establish Grey Correlation Analysis (GCA) model [10]. We can calculate grey correlation vector by following three steps.

Step1: Obtain Sub-factor Matrix

Let A_i denote the sub-factor matrix of i^{th} indicator and

$$A_i = (a_i(1), a_i(2), \cdots, a_i(n)).$$

Let B_0 denote the main-factor matrix and

$$B_0 = (b_0(1), b_0(2), \cdots, b_0(n)).$$

Step2: Obtain Grey Correlation Matrix

After standardizing the matrix A_i and matrix B_0, we can obtain grey correlation matrix of each indicator

$$D = (d_{ij}) \in \mathbb{R}^{m \times n}.$$

Step3: Calculate Correlation Vector

Let U denote the grey correlation vector, and

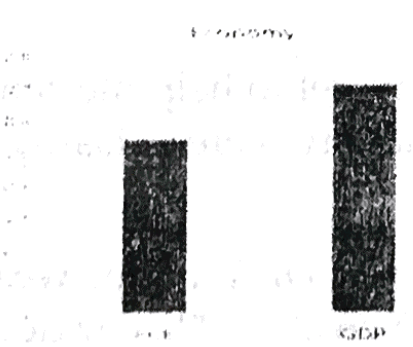
$$U = (u(1), u(2), \cdots, u(n)),$$

where

$$u(i) = \frac{1}{n} \sum_{i=1}^{n} d_{ki}.$$

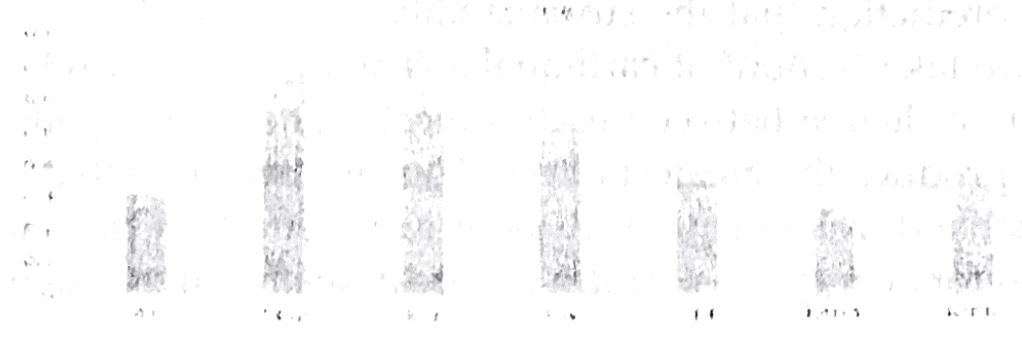
Evaluate the Most Effective Plan

In order to determine which programs or policies produce the greatest effect on the sustainability measure for Haiti, we need to find out the correlation between each indicator and the sustainability of Haiti. Firstly, we assume that in the future 10 years, Haiti will suffer the same natural disasters as Haiti earthquake (2010) does, namely, economy in Haiti will suffer the most from the natural disasters. And the change value of each indicator is also shown in Tab. 14. Since our 14 indicators are based on three themes, we firstly study the correlation between each theme and its corresponding indicators, then we figure out the correlation between each theme and the sustainability of Haiti. Through the analysis, the correlations between each theme (ecology, economy and society) and its corresponding indicators are shown in Fig. 6.



(a) The Correlation among Indicators in Economy

(b) The Correlation among Indicators in Society



(c) The Correlation among Indicators in Ecology

Figure 6: The Correlation of Three Aspects change from 2013 to 2033

Analyzing the figures, we come to the conclusion that energy use (EU) have the greatest influence on ecological sustainability efficiency. Likewise, GDP per capita (GDP) influence most on economic sustainability efficiency and improved water source (IWS) have the greatest effect on social sustainability efficiency. In general, as is shown in Fig. 7, it is ecology that exert the greatest influence on the sustainability of Haiti.

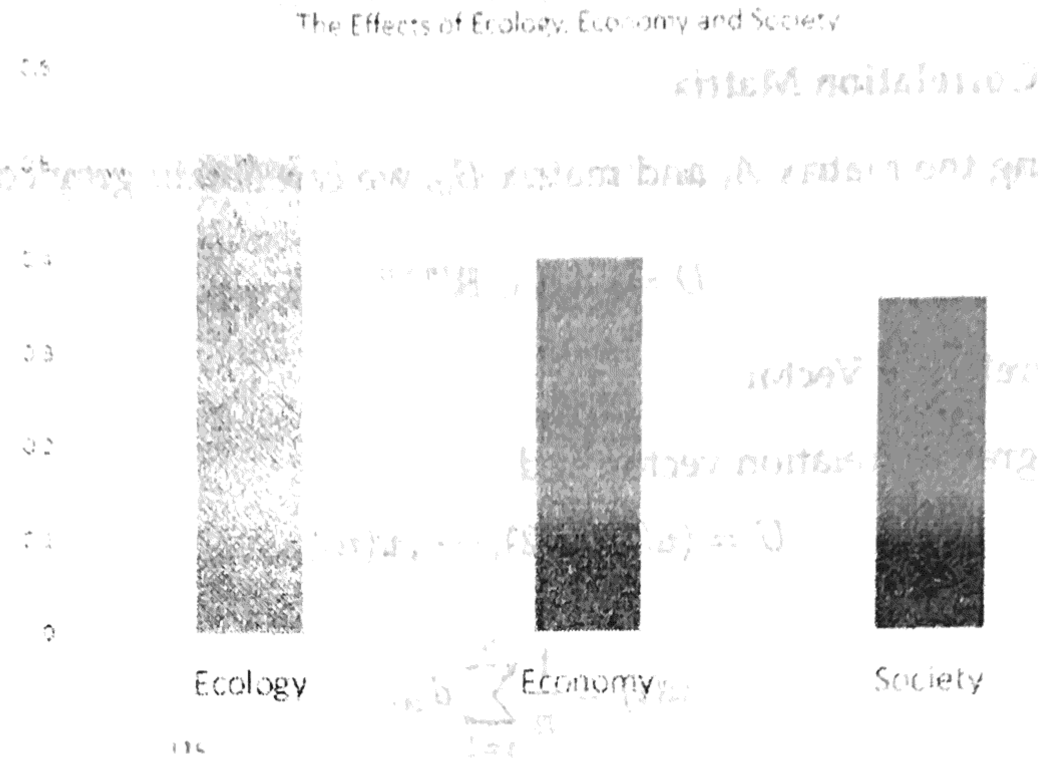


Figure 7: The Effects of Ecology, Economy and Society

Through above analysis, highly effective strategies to be implemented can be identified. In general, strategies of ecological sustainable development produce the greatest effect. Specifically, in ecology, strategies of energy use perform the greatest effect. In economy, strategies of GDP per capita produce the greatest effect. And in society, strategies of improved water source perform the greatest effect. As for detailed programs, policies, and aid that can be provided by the ICM, we have proposed them in Section 6.2.

8 Conclusion

First of all, we develop GCE model and slack-based DEA model to help measure the sustainability of a country. And we calculate 178 countries sustainability scores, classify them into four levels and rank them in terms of sustainability score.

Then, we select Haiti as an example to apply our models. Using DEA model, we obtain the sustainable development efficiency and output slacks, then we create a 20 year development plan. Thus, many strategies are mapped out.

Finally, the effect of our plan has on Haitis sustainability measure is evaluated. During the process, we make a prediction that the sustainability of Haiti will be improved after adopting our plan. Then we take account of earthquake. Through grey correlation analysis (GCA), we calculate correlation degree between each indicator and sustainability of Haiti to determine which policies produce the greatest effect. Thus we conclude that in general, strategies of ecological sustainable development exert the greatest effect on the sustainability of Haiti. Specifically, strategies for energy use perform the greatest effect in ecology.

9 Strengths and Weaknesses

9.1 Strengths

- Our indicator framework consist of 14 indicators derived from CSD indicators and is based on three themes which is defined by Dominski. So these indicators are reasonable and reliable.
- From a global perspective, we measure the sustainability of a country via GCE model and specifically, we evaluate economic, social and ecological sustainable development of a country via slack-based EDA model. Besides, our plan is also based on both two models.
- Many additional environmental factors such as earthquake and government instability are taken into account when evaluating the effect of the indicators.
- Our basic model and advanced model have strong extensibility, namely, other indicators can be added into our framework.

9.2 Weaknesses

- Due to a lack of relevant data, we make several assumptions in our work. Our models will yield a better result if we have adequate data.
- When evaluating the effect of our plan, the relative changing of other countries' sustainability is ignored.

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