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A Study on Establishing the Biharmonic Spline Interpolation Surface Based on Five SDG Pillars

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Keywords: SDGs, GRI, ESG, Biharmonic Spline Interpolation, Contour Plot

ABSTRACT

This study uses the biharmonic spline interpolation method to create surfaces that help analyze the interactions and synergies of multiple Sustainable Development Goals (SDGs). The detailed analysis reveals two unique interpolation surfaces: The Global Reporting Initiative (GRI) and Environmental, Social, and Governance (ESG). The GRI surface is formed from a linear combination of three GRI pillars, displaying two harmonic patterns. Six convex harmonics, labeled A to F, consistently score below the 0.6 level, while the concave harmonic G exceeds the 0.8 level. This surface converts complex three-dimensional data into a simpler two-dimensional GRI contour plot, which shows seven unique contours labeled A to G. A crucial boundary at the 0.7 level is introduced in the plot, which is key to identifying specific synergies within the GRI contour plot. Conversely, the ESG surface arises from the linear combination of three ESG pillars, creating 12 unique patterns, labeled A to L. Interestingly, the concave harmonics A to F consistently surpass the 0.9 level, while the convex harmonics G to L stay below the 0.7 level. The ESG surface accurately represents complex three-dimensional data, making it suitable for the contour plot. The ESG contour plot is an important analytical tool that helps identify a critical boundary set at the 0.8 level, crucial for understanding the pattern of interactions and synergies depicted in the ESG contour plot. In conclusion, the study confirms that both the GRI and ESG interpolation surfaces, along with their respective contour plots, are effective tools for analyzing the interactions and synergies among the top 100 schools featured in THE Impact Rankings.

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INTRODUCTION

The United Nations' Sustainable Development Goals (SDGs) are complex global challenges that have received considerable scholarly interest. The 2030 Agenda organizes the SDGs into five pillars (Tremblay et al., 2020), namely people, planet, prosperity, peace, and partnership. These categories serve as a framework for nations to assess their progress toward the goals. Various methodologies have been proposed by scholars to establish interaction models among the SDGs. Zelinka and Amadei (2019) used cross-impact network analysis to reveal interaction patterns within the SDGs, providing a mathematical description of their interdependencies and influences. In contrast, Henderson and Loreau (2023) emphasized the importance of a holistic approach to understanding sustainable development initiatives. They suggested incorporating the SDGs into a simplified global social-ecological model that demonstrates the significant impact of factors like population size and resource usage on the implementation of SDGs. Rist and Masoodian (2022) provided examples of interactive maps, such as network information systems, decision support systems, and computer games, to help users support the SDGs and tackle environmental issues. Soest et al. (2019) integrated the insights of SDG experts into the IAM model to create an interaction model between SDGs, facilitating stakeholder understanding of the synergies in achieving multiple SDGs at once. Poza et al. (2021) highlighted the discrepancy between the SDGs and THE rankings. They expressed significant concern about the use of high-order polynomials to model irregular datasets, which can cause oscillation problems and result in local overfitting. Therefore, choosing a suitable modeling method is essential for precise analyses. In the aforementioned literature, various mathematical methods have been applied to establish interaction models between SDGs, providing a basis for universities or businesses seeking to achieve SDGs (Singh and Rahman, 2022). However, a framework that links the SDGs with the Global Reporting Initiative (GRI) has not been thoroughly investigated (Arora et al., 2023; Sætra, 2021). To address this research gap, this case study employed the biharmonic interpolation method. This method was chosen for its ability to generate irregular surfaces, allowing for the display of interaction patterns associated with multiple SDGs. These include the five SDGs pillars, three GRI pillars, and three Environmental, Social, and Governance (ESG) pillars. By using this mathematical technique, our study aims to provide stakeholders with a variety of perspectives, assisting them in identifying universities or businesses that actively contribute to advancement of the SDGs (Dwikorawati et al., 2023). The biharmonic interpolation method, an extension of cubic or bicubic spline interpolation, operates effectively in one or two dimensions. It generates smooth, continuous curves while preserving the continuity of first- and second-order derivatives at each interpolation point. This allows it to interpolate irregular data points, facilitating the creation of surfaces. For example, this method is used to interpolate irregularly spaced data profiles from satellite altimeters. By treating each data profile individually, the method effectively mitigates long-wavelength radial orbit errors, making it invaluable for interpolating satellite altimeter data profiles (Sandwell, 1987). The biharmonic interpolation method also performs well in optimizing the trajectory of EP spacecraft transfers, minimizing cumulative ionizing radiation dose (Starchenko, 2020). In the context of interpolating irregularly spaced satellite altimeter profiles, the method enhances accuracy and coherence in height profiles due to its smoothness and minimum curvature characteristics. It also suppresses potential orbit-related errors. In contrast to high-order polynomials, the biharmonic interpolation method is well able to process irregularly spaced satellite height data profiles, ensuring stable interpolation outcomes that align closely with actual trends. It's important to note that higher order polynomials can cause oscillations when irregularly spaced data are fitted. For instance, when a high-order polynomial is combined with the Taguchi method to fit a response surface (Chen et al., 2021; Kumar et al., 2020), the use of a cubic polynomial for interpolation can lead to oscillations in both the cubic and quadratic terms of the polynomial, especially when the data interval is large. These oscillations result in sudden changes in the peaks and valleys of the curve, which do not accurately represent the actual trend of terrain changes. Therefore, biharmonic spline interpolation is a commonly applied mathematical method; it is particularly suitable for creating surfaces, and it is widely used in fields such as geospatial data and graphic design. By applying biharmonic spline interpolation to a real, two-dimensional data profile, we can combine the interpolation results for each time sample to generate a three-dimensional matrix of pseudo-three-dimensional data (Yulianto et al., 2020). Compared with two-dimensional seismic data, pseudo-three-dimensional data demonstrate geological structural characteristics, thereby reducing the uncertainty of underground interpretation and exploration risks. However, when building surfaces using biharmonic interpolation, scholars often face the problem of insufficient density of interpolation nodes, which may lead to overly smooth or discontinuous biharmonic interpolation surfaces. This is because the interpolation surface is a linear superposition combination of Green functions, and its smoothness and continuity depend on the properties of Green functions. To overcome this problem, scholars can improve areas with insufficient interpolation node density by increasing the density of measurement points or using other interpolation methods, such as bicubic spline interpolation (Hussain, 2008; Rosli et al., 2023). Such adjustments can better capture changes in irregular data while improving the smoothness and continuity of the interpolated surface.

METHODOLOGY

Biharmonic spline interpolation method: This method is used to investigate interactions and synergies among the top 100 schools listed in THE Impact Rankings in various years. The method constructs interpolation surfaces by using data points gained at different time intervals, allowing for a comparative analysis of sustainability progress over time. In formula (1), $H(p)$ represents the height of the surface, which is calculated as a weighted sum of Green functions $g(p,p_j)$ associated with each data point p_j. The Green function reflects the influence between any given point *p* and the corresponding data point p_j, while w_j indicates the weight of each data point.

$$H(p) = \sum_{j=1}^{n} w_j g(p,p_j) \tag{1}$$

Significantly, Green functions and their gradients preserve continuity in both one-dimensional and two-dimensional spaces. This continuity is used in the creation of irregular surfaces through linear combinations of Green functions. It ensures smooth transitions between data points, thereby improving the precision and dependability of the interpolated surface.

Establishing datasets based on intersection blocks encompassing multiple SDGs: The datasets are established based on intersection blocks that encompass multiple SDGs. As shown in Table 1, there are 13 intersection blocks between the five SDG pillars and the three GRI pillars. The SDGs are organized around five distinct pillars: People (covering SDGs 1–5), Prosperity (covering SDGs 6–10), Planet (covering SDGs 11–15), Peace (SDG 16), and Partnerships (SDG 17). The three GRI categories are GRI 200, which addresses economic aspects; GRI 300, which focuses on environmental concerns; and GRI 400, which deals with social dimensions. It's important to note that these three GRI pillars collectively cover the scope of the five SDG pillars, thereby creating intersection blocks between the two frameworks. Table 1 provides an analysis of the intersections between the five SDG pillars and the three GRI pillars. It highlights specific intersection blocks, such as the link between SDG 11 and GRI 200 under the planet pillar and the link between SDG 17 and GRI 200 under the partnership pillar. These intersection blocks identify specific data points that are crucial for determining the weighting factors. This process ensures that the interpolation surface accurately represents the distribution of the datasets. To provide further clarity, we can define independent factors as the five SDG pillars (people, prosperity, planet, peace, and partnership), represented as x_1 to x_5, and dependent factors are GRI 200 (GRI_Y_1), GRI 300 (GRI_Y_2), and GRI 400 (GRI_Y_3). This allows for the establishment of the intersection relationship between GRI_Y_j and x_i.

$$GRI_{Y_j} = f(x_i) \quad for \begin{cases} i = 1{\sim}5 \\ j = 1{\sim}3 \end{cases} \tag{2}$$

Similarly, based on the corresponding relationships between the five SDG pillars and three ESG pillars (Sætra, 2021), specific intersection blocks can be identified. For example, SDG 05 spans the G pillar and the people pillar, SDG 16 spans the G pillar and the peace pillar, and SDG 17 spans the G pillar and the partnership pillar. By defining independent factors (x_1 to x_5) = (people pillar to partnership pillar) and dependent factors (E_Y_1, S_Y_2, G_Y_3) = (E pillar, S pillar, and G pillar), the intersection relationship between ESG_Y_j and x_i can be expressed as follows:

$$ESG\_Y_j = f(x_i) \quad for \begin{cases} i = 1{\sim}5 \\ j = 1{\sim}3 \end{cases} \tag{3}$$

Orthogonal experimental design: Orthogonal array design is a method used to efficiently collect data and minimize the number of experimental sets needed for optimization. It is typically denoted as $OA_a(L^c)$, where a represents the number of experiments, L represents the level combination, and c represents the maximum number of control factors accommodated. This approach enables array experiments of dimension $(a \times c)$. By employing the orthogonal array design, both equations (Eq. 2 and Eq. 3) are capable of generating two-dimensional datasets denoted as (Y_1, Y_2, Y_3), as listed in Table 2. Subsequently, two-dimensional datasets are applied to construct irregular surfaces through the biharmonic spline interpolation method.

CASE STUDY

To construct these irregular surfaces, the case study follows a four-step process: (1) Data Collection: Gathering the necessary information. (2) Dataset Establishment: Forming datasets based on intersection blocks that include multiple SDGs. (3) Orthogonal Experimental Design Implementation: Applying an orthogonal experimental design. (4) GRI and ESG Interpolation Surface Creation: Developing GRI and ESG interpolation surfaces to visualize the interactions among the five SDG pillars

Table 1 Intersection blocks for establishing two-dimensional datasets based on the multiple SDGs[+]

Three GRI pillars	**People**	**Prosperity**	**Planet**	**Peace**	**Partnership**
GRI 200	SDG01/SDG03/ SDG05	SDG08-SDG10	SDG11		SDG17
GRI 300	SDG03	SDG06-SDG08	SDG11-SDG15	SDG16	SDG17
GRI 400	SDG01-SDG05	SDG08/ SDG10	SDG12	SDG16	
Three ESG pillars	**People**	**Prosperity**	**Planet**	**Peace**	**Partnership**
E pillar		SDG06/SDG07/SDG09	SDG11-SDG15		
S pillar	SDG01-SDG05	SDG06/SDG08-SDG10			
G pillar	SDG05	SDG08/SDG09	SDG11-SDG13	SDG16	SDG17

[+]*SDG01(No Poverty), SDG02 (Zero Hunger), SDG03(Good Health and Well-being), SDG04(Quality Education), SDG05(Gender Equality), SDG06(Clean Water and Sanitation), SDG07(Affordable and Clean Energy), SDG08(Decent Work and Economic Growth), SDG09(Industry, Innovation and Infrastructure), SDG10(Reduced Inequalities), SDG11(Sustainable Cities and Communities), SDG12(Responsible Consumption and Production), SDG13(Climate Action), SDG14(Life Below Water), SDG15(Life on Land), SDG16(Peace, Justice and Strong Institutions), SDG17(Partnerships). (Zelinka and Amadei, 2019)*

Data collection: The case survey, conducted from 2020 to 2023, focused on the top 100 schools as per THE Impact Rankings. The survey then categorized these universities into three distinct clusters: Cluster 1 (THE 1–50), Cluster 2 (THE 51–100), and Cluster 3 (THE 1–100). Our data collection was specifically targeted toward the SDGs that corresponded to the top four scores achieved by each university. For example, the four SDG scores of the university that ranked first in THE Impact Rankings in 2023 were as follows: 98.8 for SDG17, 96.7 for SDG15, 93.4 for SDG12, and 80.3 for SDG05.

Establishing datasets based on intersection blocks encompassing multiple SDGs: The intersection blocks are instrumental in identifying two-dimensional datasets, which are essential for determining the weighting factors. These factors ensure that the interpolation surface accurately mirrors the distribution of these points. At this stage, the datasets (Y_i) obtained at the intersection blocks are derived using Eq. (2) and (3). As a result, the datasets presented in Tables 3–8 represent the calculated number of multiple SDGs from 2020 to 2023. For example, Table 3 shows the data for GRI 200 (Y_1), which represents the number of multiple SDGs corresponding to the partnership pillar (x_5) as (59, 51, 58, 51). Similarly, Table 4 displays the number of multiple SDGs corresponding to the partnership pillar (x_5) over four years as (43, 42, 42, 40) for GRI 200 (Y_1). Table 5 provides further insights, illustrating the number of multiple SDGs corresponding to the partnership pillar (x_5) in GRI 200 (Y_1) as (102, 93, 100, 100). It's important to note that Tables 3 through 5 include datasets consisting of GRI 200, GRI 300, and GRI 400. When considering the multiple SDGs from the three-pillar ESG perspective, Tables 6–8 display the calculated number of multiple SDGs from 2020 to 2023. These tables reveal that the partnership, peace, and people pillars are not associated with the E pillar, whereas the partnership, peace, and planet pillars are not associated with the S pillar. However, Tables 6–8 present datasets consisting of the E pillar, S pillar, and G pillar.

Implementing the orthogonal experimental design: This study utilizes an orthogonal experimental design to systematically investigate the interrelationships among five SDG pillars, three GRI pillars, and three ESG pillars. This method facilitates the analysis of various factors that impact sustainability performance. The orthogonal experimental design, denoted as L_{16} (4^5), comprises 16 experimental groups. Each group is represented by independent factors, denoted as (x_i). These factors correspond to four distinct levels, each representing a year from 2020 to 2023. Eq.(2) can be expressed as Eq. (4) to establish the relationship between GRI_Y_j and x_i.

$$GRI\_Y_j = \sum_{i=1}^{5} \quad x_i \quad for \begin{cases} i = 1\sim5 \\ j = 1\sim3 \end{cases} \tag{4}$$

Following the orthogonal experimental design L_{16} (4^5), equation (4) facilitates the generation of a two-dimensional dataset (GRI_Y_1, GRI_Y_2, GRI_Y_3)= (GRI200, GRI300, GRI400), as illustrated in Figure 1. Similarly, utilizing equation (3), the relationship between ESG_Y_j and x_i is established, leading to equation (5).

$$ESG\_Y_j = \sum_{i=1}^{5} \quad x_i \quad for \begin{cases} i = 1\sim5 \\ j = 1\sim3 \end{cases} \tag{5}$$

Table 2 Identified the independent and dependent factors as well as corresponding levels

Dependence factors			**Independence factors**	**Levels**			
Y_1	Y_2	Y_3	Five SDG Pillars	L1	L2	L3	L4
GRI 200 or (E pillar)	GRI 300 or (S pillar)	GRI 400 or (G pillar)	People (x_1)/Prosperity (x_2) Planet (x_3)/Peace (x_4) Partnership (x_5)	2020	2021	2022	2023

Table3 Cluster 1 (THE 1-50) for three GRI pillars

Dependence factors	**Independence factors**					**Levels**
Three GRI pillars	Partnership (x_5)	Peace (x_4)	People (x_1)	Planet (x_3)	Prosperity (x_2)	Year
GRI 200	59	14	40	26	40	2020
	51	16	26	20	46	2021
	58	6	22	31	33	2022
	51	7	22	26	41	2023
GRI 300	0	14	19	60	37	2020
	0	16	17	48	26	2021
	0	6	10	79	28	2022
	0	7	10	66	22	2023
GRI 400	0	14	44	13	20	2020
	0	16	36	9	29	2021
	0	6	37	24	14	2022
	0	7	31	18	21	2023

Table 4 Cluster 2 (THE 51-100) for three GRI pillars

Dependence factors	**Independence factors**					**Levels**
Three GRI pillars	Partnership (x_5)	Peace (x_4)	People (x_1)	Planet (x_3)	Prosperity (x_2)	Year
GRI 200	43	17	30	8	24	2020
	42	8	28	20	22	2021
	42	8	24	21	26	2022
	40	10	21	14	32	2023
GRI 300	0	17	17	29	25	2020
	0	8	13	45	23	2021
	0	8	9	51	20	2022
	0	10	8	42	22	2023
GRI 400	0	17	46	11	16	2020
	0	8	39	11	17	2021
	0	8	30	12	16	2022
	0	10	29	18	25	2023

Table5 Cluster 3 (THE 1-100) for three GRI pillars

Dependence factors	**Independence factors**					**Levels**
Three GRI Pillars	Partnership (x_5)	Peace (x_4)	People (x_1)	Planet (x_3)	Prosperity (x_2)	Year
GRI 200	102	31	70	34	64	2020
	93	24	54	40	68	2021
	100	14	46	52	59	2022
	100	20	48	43	78	2023
GRI 300	0	31	36	89	62	2020
	0	24	30	96	49	2021
	0	14	19	130	48	2022
	0	20	21	116	49	2023
GRI 400	0	31	90	24	36	2020
	0	24	75	20	46	2021
	0	14	67	36	30	2022
	0	20	69	38	49	2023

Table 6 Cluster 1 (THE 1–50) for three ESG pillars

Dependence factors	**Independence factors**					**Levels**
Three GRI Pillars	Partnership (x_5)	Peace (x_4)	People (x_1)	Planet (x_3)	Prosperity (x_2)	Year
E pillar	0	0	0	60	39	2020
	0	0	0	48	24	2021
	0	0	0	79	39	2022
	0	0	0	66	28	2023
S pillar	0	0	44	0	43	2020
	0	0	36	0	49	2021
	0	0	37	0	49	2022
	0	0	31	0	47	2023
G pillar	59	14	13	39	38	2020
	51	16	2	29	36	2021
	58	6	8	55	27	2022
	51	7	4	44	34	2023

Subsequently, according to the orthogonal experimental design, Eq. (5) generates a two-dimensional dataset (ESG_Y_1, ESG_Y_2, ESG_Y_3) = (E pillar, S pillar, G pillar), as depicted in Figure 2. This systematic approach enables the exploration of relationships between independent factors and corresponding variables (GRI_Y_j and ESG_Y_j). By visualizing the intricate relationships within two-dimensional datasets, researchers gain a deeper understanding of how multiple factors influence the SDGs. This understanding is useful in offering valuable insights into the complex interactions between SDGs and reporting frameworks, thereby enhancing our comprehension of sustainable development dynamics.

Creation of GRI and ESG interpolation surfaces for visualizing interactions among the five SDG pillars: This method employs biharmonic spline interpolation to convert a two-dimensional dataset into a three-dimensional matrix. The process results in the formation of two unique interpolation surfaces. The case study analysis identifies these surfaces as the GRI interpolation surface and the ESG interpolation surface. These surfaces provide significant insights into the complex interactions among the five SDG pillars, the three GRI pillars, and the three ESG pillars. Moreover, these surfaces serve as graphical representations of interaction relationships, aiding in the generation of a detailed contour plot. This contour plot allows for observation of synergy patterns among the five SDG pillars.

Table 7 Cluster 2 (THE 51–100) for three ESG pillars

Dependence factors	**Independence factors**					**Levels**
Three ESG pillars	Partnership (x_5)	Peace (x_4)	People (x_1)	Planet (x_3)	Prosperity (x_2)	Year
E pillar	0	0	0	29	21	2020
	0	0	0	45	17	2021
	0	0	0	51	21	2022
	0	0	0	42	14	2023
S pillar	0	0	46	0	25	2020
	0	0	39	0	25	2021
	0	0	30	0	33	2022
	0	0	29	0	36	2023
G pillar	43	17	8	19	20	2020
	42	8	4	31	16	2021
	42	8	7	33	19	2022
	40	10	10	32	22	2023

Table 8 Cluster 3 (THE 1–100) for three ESG pillars

Dependence factors	**Independence factors**					**Levels**
Three ESG pillars	Partnership (x_5)	Peace (x_4)	People (x_1)	Planet (x_3)	Prosperity (x_2)	Year
E pillar	0	0	0	89	60	2020
	0	0	0	96	41	2021
	0	0	0	130	60	2022
	0	0	0	116	46	2023
S pillar	0	0	90	0	68	2020
	0	0	75	0	74	2021
	0	0	67	0	82	2022
	0	0	69	0	90	2023
G pillar	102	31	21	58	58	2020
	93	24	6	60	52	2021
	100	14	15	88	46	2022
	100	20	16	81	61	2023

As a result, this visual distribution facilitates a deep comprehension of the interplay among these elements. Figure 3 illustrates our utilization of the biharmonic interpolation method in analyzing a two-dimensional dataset comprising GRI200, GRI300, and GRI400. This method facilitates data processing, enabling the construction of the GRI surface through the linear combination of three GRI pillars. Utilizing this technique not only facilitates effective data processing but also enhances clarity in visualizing the GRI interpolation surface. Similarly, Figure 4 serves as a visual representation of the simulation application concerning the integration of the three ESG pillars within the SDGs. To achieve this, we utilize a two-dimensional dataset that groups the data related to these three ESG pillars. By employing a linear combination of the three ESG pillars, we construct an ESG interpolation surface. This surface facilitates a visual perspective for analyzing SDGs. In Figure 4, three distinct clusters of datasets are represented by different colors. Cluster 1 is highlighted in red, Cluster 2 in blue, and Cluster 3 in green. These clusters offer valuable insights into the interconnectedness and spatial distribution of the three ESG pillars. Figures 5 and 6 illustrate two interpolation surfaces that represent the features of terrain contours. These surfaces provide stakeholders with valuable three-dimensional perspectives, enabling them to gain deep insights into the complex interactions among three SDG pillars, three GRI pillars, and three ESG pillars.

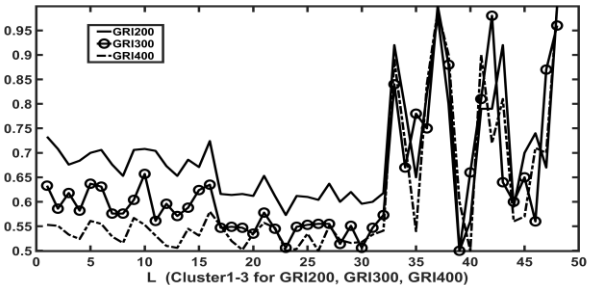

Figure 1 three GRI pillars. Cluster 1 (L axial position is from1to16), Cluster 2 (L axial position is from 17 to 32), and Cluster 3 (L axial position is from 33 to 48)

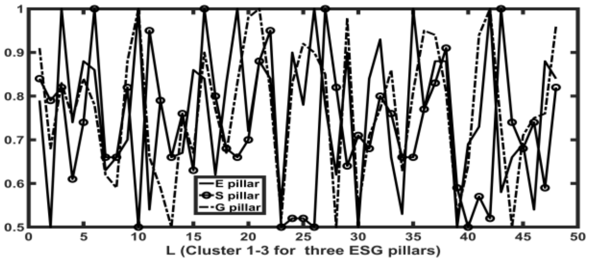

Figure 2 Three ESG pillars. Cluster 1 (L axial position is from1to16), Cluster 2 (L axial position is from 17 to 32), and Cluster 3 (L axial position is from 33 to 48)

RESULTS AND DISCUSSIONS

This study utilizes the biharmonic interpolation method to construct two irregular data surfaces: a GRI interpolation surface and an ESG interpolation surface. The datasets used are derived from the top four SDGs scores of the top 100 schools from 2020 to 2023. These schools are grouped into three clusters: Cluster 1 (schools ranked 1–50), Cluster 2 (schools ranked 51–100), and Cluster 3 (all schools). In constructing the GRI interpolation surface, the study incorporates three GRI pillars: GRI 200 (economic), GRI 300 (environmental), and GRI 400 (social). These pillars are crucial, as they facilitate successful implementation of harmonics and creation of the GRI interpolation surface. This integration is vital, as it enables the creation of a contour plot that effectively presents the data. An orthogonal experimental design L_{16} (4^5), shown in Figure 1, is used to generate three irregular data profiles: GRI 200, GRI 300, and GRI 400. These profiles are then grouped into three clusters based on their L-axis blocks: Cluster 1 (positions 1–16), Cluster 2 (positions 17–32), and Cluster 3 (positions 33–48). Figure 3 displays the GRI interpolation surface, illustrating the distribution of seven harmonics, labeled A through G. Each harmonic represents a linear combination of the three GRI pillars.

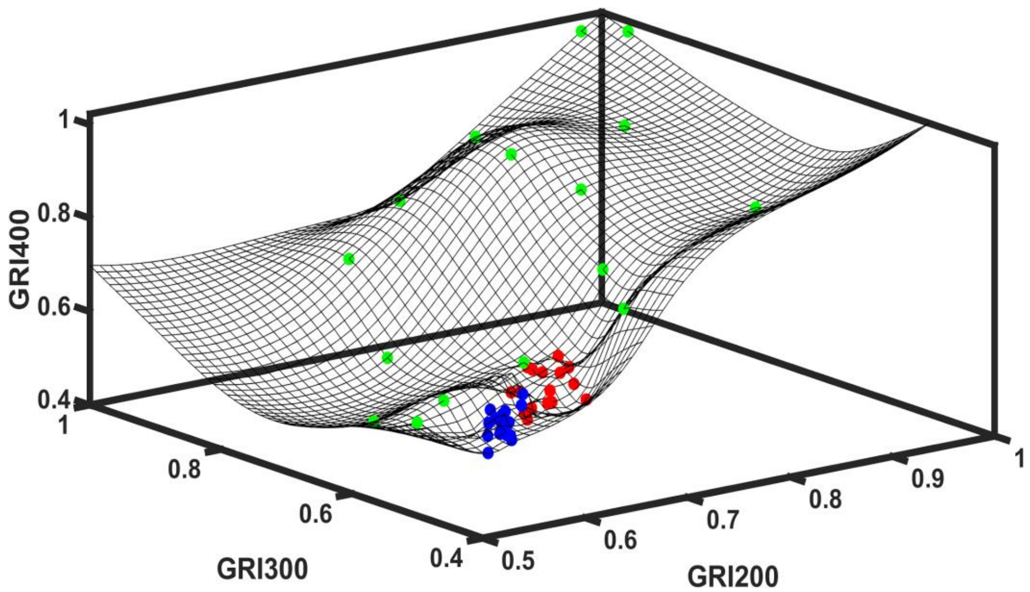

Figure 3 A GRI Interpolation surface. Where red color is the cluster1, blue color is cluster2, green color is cluster3

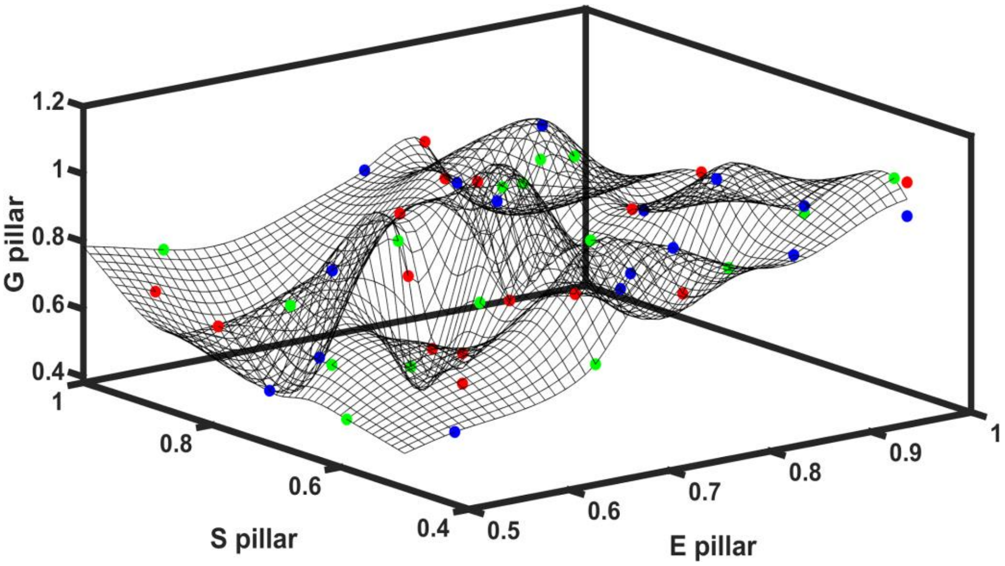

Figure 4 An ESG Interpolation surface. Where red color is the cluster1, blue color is cluster2, green color is cluster3

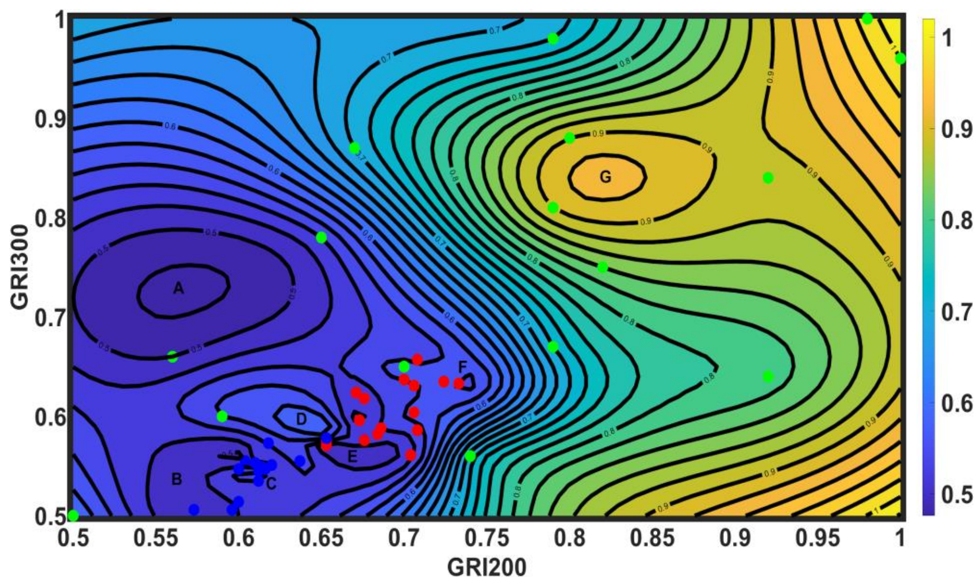

Figure 5 A GRI contour plot. Cluster 1 is marked red, Cluster 2 is marked blue, Cluster 3 is marked green.

The irregular surface of the GRI reveals two distinct patterns within its harmonics: convex harmonics A through F consistently remain below the 0.6 threshold, while the concave harmonic G notably exceeds this value, reaching levels above 0.8. Furthermore, Figure 5 introduces a critical boundary set at the 0.7 level, which plays a key role in distinguishing between the two specific synergies denoted as A through G within the GRI contour plot. This boundary aids in identifying these synergies within the plot. Specifically, it clarifies the synergies associated with concave harmonic G, which consistently appears above the 0.7 boundary, in contrast to convex harmonics A through F, which consistently appear below this boundary level. Similarly, Figure 2 introduces three irregular data profiles, namely the E pillar, S pillar, and G pillar. These profiles correspond to three distinct factors: environmental (E), social (S), and governance (G), respectively. Figure 4 illustrates the ESG interpolation surface, displaying the distribution of 12 harmonics labeled A through L. This diagram reveals unique interaction patterns among the three pillars: environmental (E), social (S), and governance (G). It's important to note that the concave harmonics (A through F) consistently show levels above 0.9, while the convex harmonics (G through L) consistently register below 0.7. In Figure 6, a critical boundary is drawn at the 0.8 level. This boundary is useful for distinguishing between two synergy distributions visible on the ESG interpolation surface.

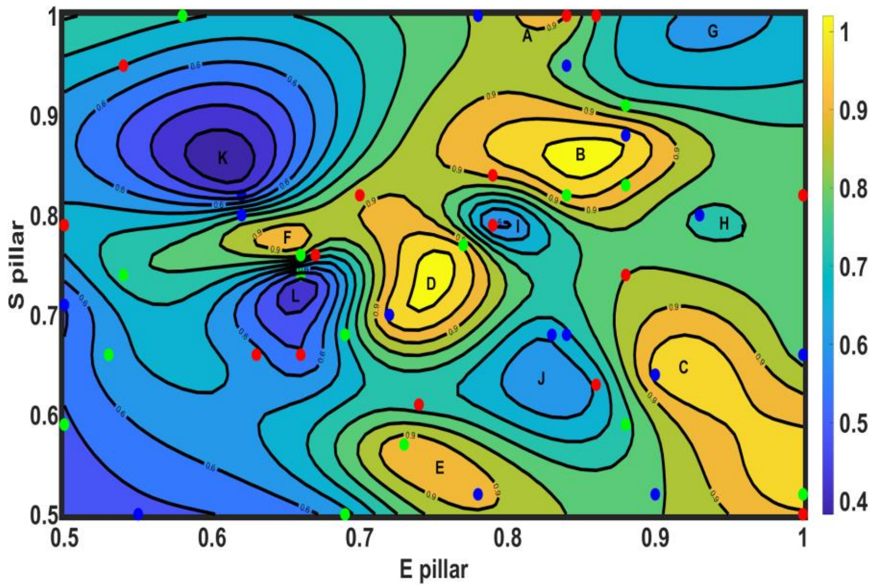

Figure 6 An ESG contour plot. Cluster 1 is marked red, Cluster 2 is marked blue, and Cluster 3 is marked green

With this boundary in place, it becomes simpler to identify and analyze the unique synergistic patterns in the ESG contour plot. Specifically, it enables consistent recognition of convex harmonics A, B, D, and F within the same level loop contour, highlighting their interconnectedness and potential for joint impact.

CONCLUSIONS

This study employed the biharmonic spline interpolation method to examine the five SDG pillars, three GRI pillars, and three ESG pillars. An orthogonal experimental design was used in a five-year case study to identify dependent and independent factors. This aided in the creation of an interpolation surface that illustrates the three GRI and three ESG pillars. The case study generated two separate data surfaces: one for GRI and another for ESG. The GRI surface consists of seven distinct harmonics, labeled A through G. Each harmonic represents a linear combination of the three GRI pillars and offers insights into the interaction patterns of multiple SDGs. Similarly, the ESG surface comprises 12 harmonics, labeled A through M, which were also derived from linear combinations of the three ESG pillars. By utilizing this method, this case study discovered that setting boundaries on the contour plots effectively highlights the distribution of synergy among the multiple SDGs. For instance, setting a boundary level of 0.7 on the GRI plot and one of 0.8 on the ESG plot enables us to distinguish the synergy distributions. The findings affirm the value of interpolation surfaces and contour plots in studying the interactions and synergies among the top 100 schools in THE Impact Rankings, which enhances understanding of the relationships between the multiple SDGs and their associated synergies.

REFERENCES

Arora H., Anwer N., Narula S., "A study of Corporate Sustainability Reporting Practices in the Indian Energy Sector," *Strategic Planning for Energy and the Environment*, 42, 529-562, (2023).

Chen, W.H., Chang, C.M., Mutuku, J.K., Lam, S., Lee,W.J., "Analysis of Microparticle Deposition in the Human Lung by Taguchi Method and Response Surface Methodology," *Environmental Research*, 197, 110975 (2021).

Dwikorawati S.S., Wicaksono A., Susetyo B., Preliminary Steps of Urban Farming Spatial Database Development for SDGs Monitoring and Evaluation in Bogor City. *Jurnal Manajemen*, 14,71-68 (2023).

Hussain M. Z. and Hussain M., "Convex Surface Interpolation," *Lecture Notes in Computer Science*, 4975, 475-482 (2008).

Henderson K., Loreau M., "A model of Sustainable Development Goals: Challenges and Opportunities in Promoting Human Well-being and Environmental Sustainability," *Ecological Modelling*, 475, 110164 (2023).

Kumar, T., Mohsin, R., Majid, Z.A., Ghafir, M.F.A., Wash, A. M., "Experimental Study of the Anti-Knock Efficiency of High-Octane Fuels in Spark Ignited Aircraft Engine Using Response Surface Methodology," *Applied Energy*, 259, 114150 (2020).

Poza E.D.L., Merello P., Barberá A., Celani A., "Universities' Reporting on SDGs: Using THE Impact Rankings to Model and Measure Their Contribution to Sustainability," *Sustainability*, 13, 2038 (2021).

Rist, T., Masoodian, M., "Interactive Map Visualizations for Supporting Environmental Sustainable Development Goal," *Sense, Feel, Design*, 13198, 36-46 (2022).

Rosli S.N.I., Zulkifly M.I.E., "Neutrosophic Bicubic B-spline Surface Interpolation Model for Uncertainty Data," *Neutrosophic Systems with Applications*, 10, 25-34 (2023).

Sandwell D., "Biharmonic Spline Interpolation Of GEOS-3 and SEASAT Altimeter Data," *Geophysical Research Letters*, 14, 139-142 (1987).

Soest, H.V., Vuuren D.V., Hilaire J., Minx J., Mathijs Minx J., Harmsen M., Krey V., Popp A., Riahi K., "Analysing interactions among Sustainable Development Goals with Integrated Assessment Models," Global Transitions, 1, 210-225(2019).

Starchenko A., "Biharmonic Spline Interpolation of Spatial Dose Rate Distribution in the Minimum Dose Trajectory Optimization Problem," *IOP Conf. Series: Materials Science and Engineering*, 927, 012056 (2020).

Sætra H., "A Framework for Evaluating and Disclosing the ESG Related Impacts of AI with the SDGs," *Sustainability*, 13, 8503(2021).

Singh A., Rahman Z., "Stakeholder Engagement and Corporate Performances: Empirical Evidence from an Emerging Economy," *Corporate Ownership & Control*, 19, 141-152 (2022).

Tremblay D., Fortier F.,Boucher J.F., Olivier Riffon, Villeneuve C., "Sustainable Development Goal Interactions: An Analysis Based on the Five Pillars of the 2030 Agenda," *Sustainable Development*, 28,1519-1826 (2020).

Yulianto, E., Abdullah, F., Novrizal, N., Riyanto A., "Pseudo 3D Seismic using Biharmonic Spline Interpolation." *IOP Conf. Series: Earth and Environmental Science*, 481, 012054 (2020).

Zelinka D., Amadei B., "Systems Approach for Modeling Interactions Among the Sustainable Development Goals Part 1: Cross-Impact Network Analysis," *International Journal of System Dynamics Applications*, 8, 23-40 (2019).

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基於五個 SDG 支柱建立雙調和樣條插值面的研究

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摘要

本研究使用雙調和樣條插值方法來建構曲面，幫助分析多個永續發展目標 (SDG) 的相互作用和協同作用。詳細分析揭示兩個獨特插值面：全球報告倡議 (GRI) 和環境、社會和治理 (ESG)。GRI 表面由三個 GRI 柱的線性組合產生，顯示兩種諧波圖案。六個凸諧波（標記為 A 到 F）始終低於 0.6 級別，而凹諧波 G 則超過 0.8 級別。該表面將複雜的三維資料轉換為簡單的二維 GRI 等高線圖，該圖標記 A 到 G 的七個獨特等高線。圖中引入 0.7 級別的關鍵邊界，這是識別 GRI 等高線圖內特定協同作用的關鍵。相反，ESG 表面由三個 ESG 支柱的線性組合產生，形成 12 種獨特的圖案，標記為 A 到 L。有趣的是，凹諧波 A 至 F 始終超過 0.9 級別，而凸諧波 G 至 L 保持在 0.7 級別以下。 ESG 曲面準確地表示複雜三維數據，使其適合繪製等值線圖。ESG 等值線圖是一種重要的分析工具，有助於識別 0.8 級別的關鍵邊界集，這對於理解 ESG 等值線圖中描繪的相互作用和協同作用模式至關重要。總之，本研究證實，GRI 和 ESG 插值面及其各自的等高線圖都是分析泰晤士報影響力排名前 100 名學校之間相互作用和協同作用的有效工具。