

THE STATISTICAL APPROACH TO UNDERSTANDING THE INTERDEPENDENCIES AMONG SUSTAINABLE DEVELOPMENT GOALS

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ABSTRACT

This paper comprehensively analyses the interdependencies among the Sustainable Development Goals (SDGs) through Canonical Correlation Analysis (CCA). By categorizing SDGs into Social Development Goals, Environmental Sustainability Goals, and Economic Development and Sustainable Growth Goals, the study illuminates the complex dynamics and mutual influences within these categories. The empirical findings from CCA reveal significant, statistically robust correlations that highlight synergistic and antagonistic interactions among the SDGs, which are critical for effective policy-making and strategic planning. The research underscores the importance of a holistic approach to understanding the SDG framework, advocating for integrated policy frameworks that account for the intricate interconnections between different goal sets. For instance, SDG7 (Affordable and Clean Energy) progress supports environmental objectives and enhances economic and social inclusion outcomes. The analysis thus provides crucial insights into how advancements in specific goals can facilitate or hinder progress in others, emphasizing the necessity for a balanced and informed approach to SDG implementation. The findings contribute to the academic and practical understanding of SDGs, offering strategic insights for coherent and effective policy-making that can optimize the collective pursuit of all goals. This paper serves as a valuable resource for policymakers, practitioners, and researchers involved in planning and implementing sustainable development initiatives, ensuring that efforts are comprehensive and aligned with the systemic interactions of the SDGs.

Keywords: Sustainable Development Goals, canonical correlation analysis, interdependences, policy integration, sustainable growth

1. INTRODUCTION

The Sustainable Development Goals (SDGs) represent a transformative global agenda established by the United Nations in 2015 to address a wide range of social, economic, and environmental challenges facing our world (Yusuf et al., 2024). Comprising 17 interlinked goals, the SDGs aim to eradicate poverty, improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests. These goals provide a blueprint for achieving a better and more sustainable future for all by 2030. Understanding these goals' complexities and interconnected nature is crucial for devel-

oping effective strategies that can address the multiple dimensions of sustainable development. Research into the SDGs consistently underscores the inherent interconnectedness of the goals. It suggests that progress in one area can significantly influence outcomes in others. This interdependence implies that isolated actions may be less effective or even counterproductive if the broader system of interactions is not considered. For instance, strategies to enhance economic growth (SDG8) must be aligned with measures to ensure environmental sustainability (SDG13) and reduce inequalities (SDG10). This underscores the urgency and importance of a holistic and integrated approach to realizing the SDGs, necessitating sophisticated analytical tools and frameworks to examine the synergies and trade-offs between different goals.

This paper is a significant contribution to the academic discourse on SDGs. It delves into the relationships among the goals using Canonical Correlation Analysis (CCA), a statistical method that explores the relationships between two sets of variables. By applying CCA to the SDGs, this study uncovers the latent structures that underpin their interconnections, providing insights that can make it more cohesive and effective policymaking. This analysis not only aids policymakers and practitioners but also enriches the academic understanding of the complex dynamics among the SDGs, highlighting the value and relevance of this research in the field of sustainable development and policymaking.

2. LITERATURE REVIEW

According to Nilsson et al. (2018), preliminary applications of the SDG interactions framework demonstrate potential in linking scientific research with policymaking for the SDGs. This framework achieves this by structuring policy-relevant knowledge and promoting collaborative learning among various stakeholders. For policymaking to be effectively informed, it is imperative to consider contextual factors during the assessment process.

Recent research has emphasized the intricate nature of the Sustainable Development Goals (SDGs), demonstrating the necessity for holistic approaches. For instance, Le Blanc (2015) illustrates how advancements in one goal can substantially influence others, thereby underscoring the importance of integrated strategies. Similarly, studies by Nilsson et al. (2016) and Satterthwaite et al. (2019) explore the connections between poverty eradication, sustainable urban development, and climate action, highlighting the practical implications for urban sustainability and achieving multiple developmental objectives.

The literature further identifies cross-cutting themes integral to the SDGs, including gender equality, social inclusion, and human rights. For example, Alkire et al. (2020) investigate the intersectionality of gender and poverty (SDG5 and SDG1), underscoring those empowering women and girl is essential for poverty reduction and sustainable development. Similarly, studies by Langford et al. (2018) and Gellers et al. (2021) highlight the connection between human rights (SDG16) and environmental sustainability (SDG15), stressing the importance of participatory governance and inclusive decision-making processes.

Understanding the interconnectedness of the Sustainable Development Goals (SDGs) is crucial for developing coherent policy frameworks and strategies. Recent research by Griggs et al. (2014) and Sachs et al. (2019) supports integrated approaches that consider the interrelationships among the economic, social, and environmental dimensions of sustainable development. Additionally, studies by Steffen et al. (2015) and Folke et al. (2020) emphasize the urgent need for transformative change, advocating for immediate and systemic reforms to address the fundamental causes of unsustainable development patterns.

Furthermore, scientific literature underscores the importance of comprehending the topology of the Sustainable Development Goals (SDGs) to advance sustainable development efforts

(Marino, 2022). By mapping interconnections, identifying synergies and trade-offs, analyzing complex system dynamics, and integrating multidisciplinary perspectives, policymakers and practitioners can devise more effective strategies to achieve the SDGs and promote global well-being. Various methodologies have been employed to map these interconnections and identify synergies and trade-offs. For example, Le Blanc (2015) discusses the use of network analysis techniques to visualize the relationships between different SDGs, demonstrating how progress in one goal can affect others. Nilsson et al. (2016) emphasize mapping the interactions between SDGs to understand their interlinkages and optimize policy interventions.

Griggs et al. (2014) highlight how addressing poverty (SDG1) can positively contribute to achieving other goals, such as health (SDG3) and education (SDG4), illustrating beneficial synergies. Conversely, Langford et al. (2018) explore the trade-offs between economic growth (SDG8) and environmental sustainability (SDG13), stressing the necessity for balanced approaches. Scholars have applied complex science and systems thinking to analyze the dynamics of the SDGs' topology and understand emergent properties. For instance, Steffen et al. (2015) discuss the concept of planetary boundaries, identifying critical thresholds for Earth system processes and their implications for sustainable development.

The literature on the topology of the Sustainable Development Goals (SDGs) draws on multidisciplinary perspectives, including economics, environmental science, sociology, and public policy. The structure of the SDGs is characterized by an intricate interplay of synergies and trade-offs. A key element in this system is the importance of sustainable energy (SDG7), which is essential for supporting other objectives but also presents challenges related to responsible consumption and production (SDG12) (Nerini et al., 2017; Fonseca et al., 2020; Kwilinski et al., 2024). Efforts to reduce poverty and improve health outcomes align well with numerous goals, underscoring the interconnected nature of the SDGs (Pradhan et al., 2017). However, trade-offs, particularly with SDG12, highlight the need for comprehensive and strategic approaches to policy formulation and implementation. The SDGs are not merely a collection of individual targets but a system that requires a thorough understanding of how each objective influences the others (Swain & Ranganathan, 2021).

McCollum et al. (2018) examined the energy-related interconnections among the Sustainable Development Goals (SDGs), highlighting the substantial overlap between energy policies and other SDGs. Their research demonstrates how advancements in energy can stimulate progress across multiple goals (Arzu & Yasaman, 2024). Janoušková, Hák, and Moldan (2018) address the complexities and sometimes confusing nature of global SDG assessments, emphasizing that a better understanding of the relationships among the SDGs is essential for effective communication and implementation of sustainability strategies. Van Soest et al. (2019) employed integrated assessment models to analyze SDG interactions, underscoring the value of model-based approaches in understanding and prioritizing SDG targets. Their work provides a structured method for anticipating the impacts of various sustainability policies.

Dörgö, Sebestyén, and Abonyi (2018) utilized causality analysis to investigate the cause-and-effect relationships among the Sustainable Development Goals (SDGs). Their findings underscore the intricate nature of these interactions and the necessity for sophisticated analytical tools to inform policymaking. Alkire et al. (2020) examine the intersectionality of gender inequality (SDG5) and poverty (SDG 1), emphasizing the importance of integrated approaches to address multiple dimensions of deprivation. Satterthwaite & Tacoli (2019) explore urbanization (SDG11) and its implications for sustainable development, highlighting the critical role of interdisciplinary collaboration.

Understanding the SDGs' topology has significant implications for policy formulation and implementation (Kuzmak & Kuzmak, 2023). Sachs et al. (2019) stress the importance of inte-

grated policy approaches that consider the interconnections between different goals. Gellers et al. (2021) discuss the role of human rights (SDG16) in shaping environmental sustainability (SDG15) outcomes, emphasizing the need for participatory governance and inclusive decision-making processes.

SDG3 is a cornerstone for fostering a sustainable, human-centered society by ensuring healthy lives and promoting well-being across all age groups. Its significance lies in cultivating a societal ethos that prioritizes the welfare and advancement of every individual, aligning with fundamental facets of societal advancement (Arslan & Kekeç, 2023; Liashenko & Dluhopolski, 2024; Dvulit et al., 2024; Zatonatska et al., 2024; Hamdan Al-Abbadi et al., 2025). Conversely, the emphasis on the interplay between the environment and human activities profoundly shapes SDG interactions. Scharlemann et al. (2020) underscore the critical role of the environment and its interconnectedness with human endeavors in influencing the attainment of the SDGs. According to their perspective, policymakers can discern opportunities to capitalize on synergies and mitigate trade-offs among specific SDGs by acknowledging the nexus between the environment and human activities. This approach underscores the imperative of effective environmental management in implementing all SDGs and guides national and international endeavors to address the interlinkages among the goals.

The paper by Nilsson (2018) introduces a conceptual framework to map and evaluate interactions among the Sustainable Development Goals (SDGs). This framework underscores the significance of comprehending interactions between the SDGs' adverse (trade-offs) and advantageous (co-benefits) aspects. It incorporates a typology and scoring system for interactions on a 7-point scale, delineating the nature of binary relationships among SDGs at the target level. Moreover, the framework accounts for key contextual determinants and influences of interactions, such as governance structures, geographical settings, implementation technologies and policies, and temporal considerations. Additionally, it highlights the directionality of interactions, discerning between uni-directional and bi-directional but asymmetric dynamics.

Moallemi et al. (2022) discussed qualitative and quantitative methods to analyze the causal links and interactions among SDGs in various sectors, such as bioenergy, agriculture, and land use. They introduce the concept of archetypes as a systemic approach to qualitatively frame and analyze SDG interactions, providing a generalized understanding of recurring patterns and their underlying causal drivers. Researchers emphasize the importance of quantitative assessment in understanding the complex dynamics of SDG interactions and their impacts. Moallemi et al. (2022) also highlights the need for more straightforward, qualitative tools to support decision-makers and organizations with limited resources.

3. AIM OF THE RESEARCH

The paper explores the interconnectedness of the Sustainable Development Goals (SDGs) and emphasizes the need for a holistic approach to sustainable development. It categorizes the SDGs into Social Development Goals, Environmental Sustainability Goals, and Economic Development and Sustainable Growth Goals, highlighting their complex interplay.

This study examines the intricate interconnections among the Sustainable Development Goals (SDGs), providing insights into the comprehensive approach necessary for sustainable development.

The document underscores the importance of understanding the relationships between the SDGs for effective policymaking and implementation, advocating for integrated approaches and transformative change. It emphasizes the significance of sustainable energy (SDG7) in supporting other objectives and highlights the need for comprehensive and strategic approaches to policy formulation and execution.

4. METHODS

Given SDGs' interconnected nature, our research aims to rigorously assess the latent factor structures underpinning these linkages, providing a clearer understanding of their complex dynamics. By identifying these underlying structures, we seek to illuminate the synergies and trade-offs among the SDGs, offering strategic insights for more cohesive and effective policymaking. This approach is crucial for devising integrated strategies to address the multi-dimensional challenges of sustainable development, ensuring that efforts are comprehensive and scientifically grounded in understanding the systemic interactions of the SDGs.

Using SDG scores as variables to gauge progress in SDG achievement by countries offers a holistic and standardized framework for evaluating advancement across multiple dimensions of sustainable development (UN, 2023). These scores, attained by aggregating various indicators into a unified metric, furnish a comprehensive overview of overall performance toward SDG attainment. They facilitate progress comparisons within and among countries, regions, and sectors.

Our methodology for unveiling interconnections among the Sustainable Development Goals (SDGs) employs Canonical Correlation Analysis (CCA), a sophisticated statistical technique tailored to discern and quantify relationships between two sets of variables. Within the SDG context, we apply CCA to empirically investigate how progress in one set of goals may correlate with advancements in another. This approach enables us to extract paired sets of canonical variates, representing combinations of SDGs exhibiting the highest correlation, thereby offering a clear empirical depiction of interconnections among the goals. Through this analysis, we can effectively discern and interpret the underlying patterns and linkages driving interactions across different sustainability objectives, thereby providing valuable insights for targeted and integrated policy interventions.

In canonical correlation analysis, the factor structure denotes the pattern of relationships between variables in two sets. It elucidates how variables from one set relate to those from the other through these canonical variates. Canonical loadings typically illustrate the factor structure, signifying the strength and direction of the relationship between each variable and the canonical variate. These loadings shed light on which variables predominantly contribute to the relationship between the sets and aid in identifying underlying patterns or dimensions of association.

Understanding the factor structure in canonical correlation analysis is not merely a theoretical exercise but a practical necessity. It serves as the linchpin for interpreting relationships between variables and unveiling meaningful patterns or constructs that expound their association.

5. RESULTS

The correlation heatmap visualizes the relationships between the 17 SDG scores across 168 countries (Figure 1).

The correlation heatmap generally indicates diverse relationships among the Sustainable Development Goals (SDG) scores. Several SDGs show a strong positive correlation, suggesting that progress in one area may be associated with progress in another. This could imply that certain SDGs have synergistic effects, where advancements in specific goals aid in the advancement of others. Conversely, several SDGs also display negative correlations, albeit fewer and less intense than the positive ones. This suggests that improvement in some goals may occur independently or even at the expense of others, indicating potential trade-offs in policy and implementation strategies.

Both strong positive and negative correlations suggest a complex interplay between the SDGs, where achieving a balance may require integrated and nuanced approaches. This complexity

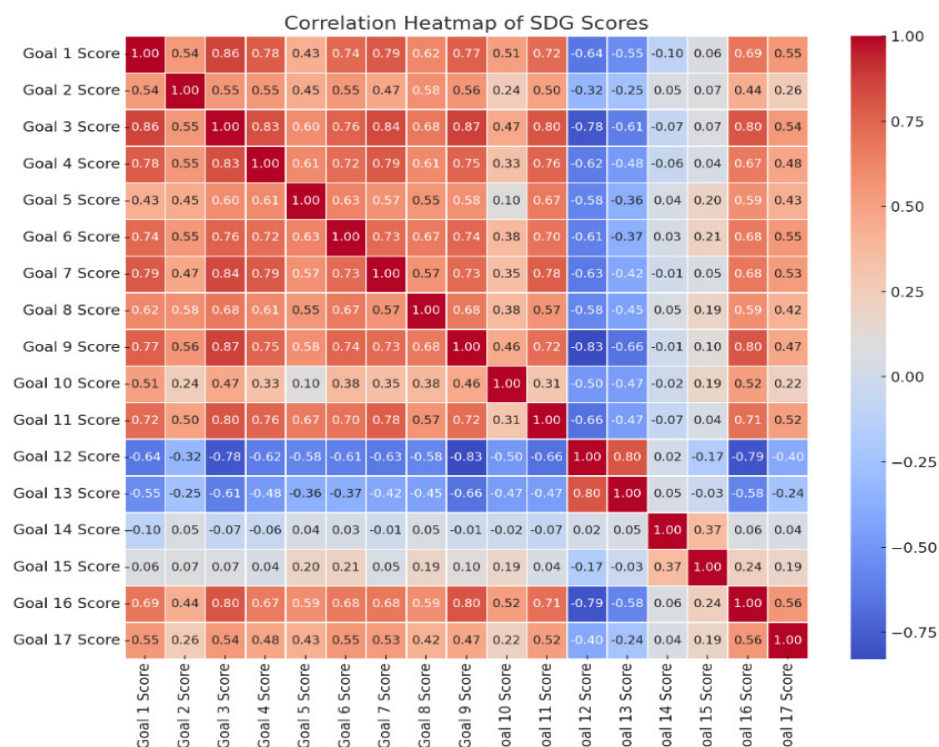
emphasizes the need for strategic planning that considers the interconnected nature of these goals to ensure that progress in one area does not hinder development in another. Overall, the heatmap underlines the importance of a holistic view in pursuing sustainable development. However, the precise nature of these relationships would require a more detailed investigation beyond the scope of this heatmap's immediate visual representation.

Theoretical framework

The SDGs we concentrate on encompass SDG1, SDG2, SDG3, SDG4, SDG5, SDG6, SDG7, and SDG11, collectively termed “Social Development Goals”. This designation underscores the pivotal role of these goals, which encapsulate societal advancement, well-being, and equality.

We emphasize the significance of SDG7, which centers on ensuring universal access to affordable, reliable, sustainable, and modern energy. From our perspective, energy is a fundamental human necessity essential for tasks such as home cooking, heating, and lighting, profoundly influencing daily living conditions and overall welfare. In many regions worldwide, access to clean and secure energy sources is critical in averting health issues from indoor air pollution and hazards associated with unsafe cooking practices. Conversely, dependable energy sources alleviate the time burden associated with fuel collection, often conducted under hazardous circumstances. This burden disproportionately affects women and children, underscoring how energy access is pivotal in enhancing safety and health. Access to electricity extends productive hours for students and workers alike, facilitating evening studies for children and enabling adults to engage in economic pursuits, directly contributing to other human-oriented goals such as Quality Education (SDG4) and Decent Work and Economic Growth (SDG8).

Figure 1. Correlations among SDG scores



Source: own calculations based on SDGs Scores 2023 dataset

Energy poverty emerges as a crucial facet of inequality, with individuals lacking access to en-

ergy often experiencing marginalization across various dimensions, including economic and social realms. Addressing energy access can serve to alleviate broader inequalities (SDG10). Given these considerations, while SDG7 predominantly focuses on infrastructure and economic aspects of energy, its ramifications on human life, health, safety, and social equity strongly advocate for its recognition as a human-oriented goal. This dual classification underscores the interconnectedness of the SDGs, wherein progress in one domain frequently facilitates advancements in others.

SDG13, SDG14, and SDG15 are dedicated to environmental sustainability and are thus collectively termed “Environmental Sustainability Goals.” This designation reflects the overarching theme of these objectives, primarily concerned with safeguarding the planet, preserving natural resources, and combating climate change.

On the other hand, SDG8, SDG9, SDG10, and SDG12 encompass a range of topics related to economic development, industry, innovation, infrastructure, and sustainable consumption and production. We have classified this group of SDGs as “Economic Development and Sustainable Growth Goals”. This categorization emphasizes the promotion of inclusive economic growth, the advancement of innovation and infrastructure, the assurance of decent work and economic opportunities, and the fostering of sustainable consumption and production patterns.

Social Development Goals vs Environmental Sustainability Goals

Table 1 displays the outcomes of a Canonical Analysis conducted on the SDGs Scores 2023 dataset. Canonical Analysis is a statistical method employed to examine relationships between two sets of variables. In this analysis, two sets of variables are delineated: the left set and the right set.

Table 1. Canonical Analysis Summary Social Development Goals vs Environmental Sustainability Goals

	Canonical R=0.72 Chi ² (24) =84.214 p=0.0000	
	Left Set	Right Set
No. of variables	8	3
Variance extracted	68.3095%	100.000%
Total redundancy	30.9607%	23.0195%
1	Goal 1 Score	Goal 15 Score
2	Goal 2 Score	Goal 14 Score
3	Goal 3 Score	Goal 13 Score
4	Goal 5 Score	
5	Goal 6 Score	
6	Goal 7 Score	
7	Goal 11 Score	
8	Goal 4 Score	

Source: own calculations

The Canonical R-value, a key indicator of the strength of the relationship between the two sets of variables, is 0.72, signifying a moderate positive correlation. The Chi-square test statistics, a crucial measure with 24 degrees of freedom, stands at 84.214, and the associated p-value is 0.000, indicating a highly significant relationship.

The relationships between the variables in the left and right sets explain about 68,31% of the variation in the left set. Total redundancy, about 31%, represents the percentage of variability in the left set that is not accounted for by the canonical correlation. This suggests that other factors not included in the analysis contribute to the variability observed in the left set beyond

its relationship with the variables in the right set. Notably, 100% of the variance is extracted in the right set. This indicates that the canonical correlation with the left set can explain all the variability in the right set of variables. In other words, the relationships between the variables in the right set and those in the left set account for all the variability observed in the right set. The total redundancy is 23,0195%, representing the percentage of variability in the right set that is not accounted for by the canonical correlation. Like the left set, this suggests that additional factors or variables not included in the analysis may contribute to the variability observed in the right set beyond its relationship with the variables in the left set.

In this instance, Root 1 (Table 2) exhibits the highest eigenvalue, elucidating the largest variance among the SDG scores. Conversely, Root 3 manifests the lowest eigenvalue, implying that it explains the least variance. This insight is pivotal for comprehending the relative importance of each factor or component in the analysis.

Table 2. Eigenvalues for canonical roots Social Development Goals vs Environmental Sustainability Goals

Root	Eigenvalues (SDG Scores)		
	Root 1	Root 2	Root 3
Value	0.514062	0.103106	0.011581

Source: own calculations

Table 3 presents the outcomes of Chi-Square Tests with Successive Roots Removed from the Canonical Correlation Analysis (CCA). For the initial root, the canonical correlation (R) is approximately 0.717, indicating a significant relationship between the variables in the canonical variable. The canonical R-square is 0.514, suggesting that the predictors account for 51.4% of the variance. The chi-square statistics associated with this model amounts to 84.214, with 24 degrees of freedom, yielding a highly significant p-value. This outcome underscores the statistical significance of the model.

Table 3. Chi-Square Tests with Successive Roots Removed Social Development Goals vs Environmental Sustainability Goals

Root Removed	SDGs Scores					
	Canonical R	Canonical R-sqr.	Chi-sqr.	df	p	Lambda Prime
0	0.716981	0.514062	84.21399	24	0.000000	0.430788
1	0.321102	0.103106	12.04667	14	0.602555	0.886507
2	0.107617	0.011581	1.16489	6	0.978581	0.988419

Source: own calculations

However, the proportions of variance extracted by the roots (Table 4) indicate that Root 1 is the most influential in explaining the variance in the left set of SDG scores.

Table 4. Variance Extracted (Proportions) Social Development Goals vs Environmental Sustainability Goals

Root/Factor	Variance extracted	Redundancy
<i>Left set</i>		
Root 1	0.591392	0.304012
Root 2	0.049531	0.005107
Root 3	0.042172	0.000488
<i>Right set</i>		
Root 1	0.361707	0.185940
Root 2	0.402768	0.041528
Root 3	0.235525	0.002728

Source: own calculations

Root 1 extracts approximately 59.14% of the total variance in the left set, indicating that this root accounts for a substantial portion of the variability in the left set. The redundancy value associated with Root 1 is 0.304, suggesting some overlap between the factors extracted by Root 1 and those extracted by other roots. Only about 4.95% of the total variance is extracted for Root 2, indicating that this root explains a relatively small amount of the variability in the data of the left set. The redundancy value associated with Root 2 is very low, at 0.005, indicating minimal overlap or duplication with other factors. Similarly, Root 3 extracts approximately 4.22% of the total variance, with an even lower redundancy value of 0.0005. This suggests that Root 3 explains a small amount of unique variability in the left set's data, with little overlap with other factors.

Simultaneously, Root 1 explains approximately 36.17% of the variance in the observed variables in the right set. The redundancy values suggest that Root 1 primarily contributes to this variance. Root 2 explains approximately 40.28% of the variance in the observed variables. The redundancy values are also low, indicating that Root 2 is the dominant source of variance for these variables. Root 3 explains approximately 23.55% of the variance in the right set's observed variables, and similar to Roots 1 and 2, the redundancy values are low.

These results indicate that each root explains a substantial portion of the variance in the observed variables, with minimal redundancy across roots. This suggests that each root captures unique aspects of the underlying structure of the SDG scores represented in the right set. However, Root 3 should not be considered due to its low eigenvalue and weak significance tests (Table 2).

Table 5 presents the structure of the factor for each variable in the left set of CCA across roots. For Root 1, the Goal 3 score has the highest loading of 0.939, indicating a strong positive association with this root. Goal 5 score (loading of 0.828) and Goal 6 score (loading of 0.780) also have strong positive loadings, suggesting significant correlations with Root 1. Goal 4 score (loading of 0.774) and Goal 1 score (loading of 0.741) also show substantial positive associations with Root 1.

Table 5. Factor Structure Left Set Social Development Goals vs Environmental Sustainability Goals

Root Variable	SDGs Scores		
	Root 1	Root 2	Root 3
Goal 1 Score	0.741200	0.138030	-0.396606
Goal 2 Score	0.423738	-0.366839	0.054079
Goal 3 Score	0.939349	0.055949	-0.111387
Goal 5 Score	0.828158	-0.255776	0.236428
Goal 6 Score	0.779691	-0.355504	-0.069631
Goal 7 Score	0.750446	-0.144883	-0.103503
Goal 11 Score	0.815002	0.142755	0.295077
Goal 4 Score	0.773736	0.079524	-0.078835

Source: own calculations

For Root 2, the Goal11 Score has the highest loading of 0.138, although it is relatively low compared to the loadings in Root 1. Goal11 Score also exhibits a moderate positive loading of 0.143, while Goal7 score has a small negative loading of -0.145, indicating a weak inverse association with Root 2. Overall, these results suggest that Goal3 score, Goal5 score, and Goal6 score are the most influential variables in explaining Root 1, while Goal11 score plays a more significant role in Root 2. Goal1 score, Goal4 score, and Goal7 score have weaker associations across all roots.

Table 6 presents the factor structure for the right set of CCA across roots. For Root 1, the Goal15 score has a factor loading approximately 0.356, suggesting a moderate positive associ-

ation with Root 1. Goal14 score has a negligible factor loading (-0.036), indicating a weak negative association with Root 1. Goal13 score has a strong negative loading (-0.978), indicating a significant negative association with Root 1. For Root 2, the Goal15 score has a substantial negative loading (-0.895), indicating a strong negative association with Root 2. Goal14 score has a moderate negative loading (-0.634), indicating a significant negative association with Root 2. Goal13 score has a negligible factor loading (-0.076), suggesting a weak negative association with Root 2.

Table 6. Factor Structure Right Set Social Development Goals vs Environmental Sustainability Goals

Root Variable	Factor Structure. right set (SDGs Scores)		
	Root 1	Root 2	Root 3
Goal 15 Score	0.356423	-0.894877	-0.268623
Goal 14 Score	-0.035836	-0.633802	0.772665
Goal 13 Score	-0.978162	-0.076116	-0.193407

Source: own calculations

In summary, each root (as a pair of canonical variants CV) represents distinct patterns of association between the right-set variables and the underlying latent factors. At the same time, the canonical weights of variables in each set (Table 7) indicate how much each variable contributes to the relationship between the two sets of variables.

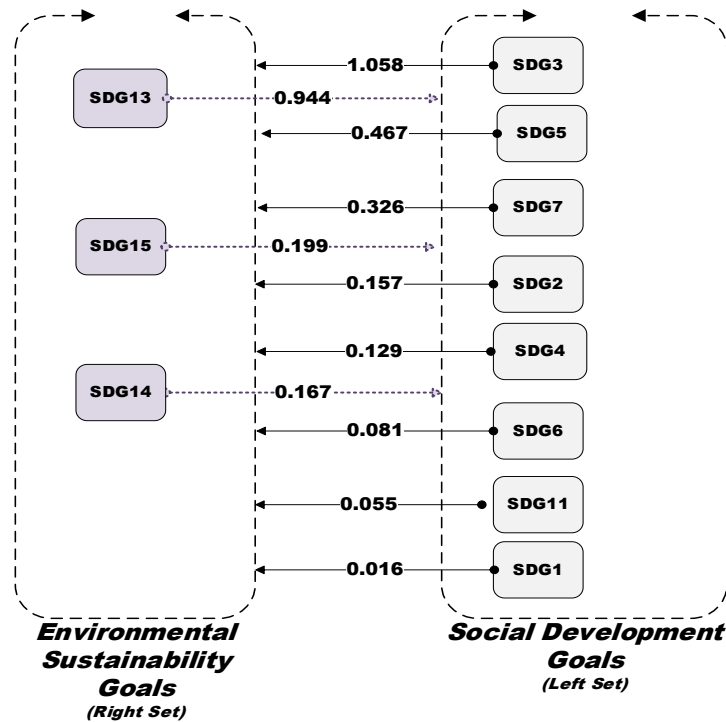
Table 7. Canonical Weights Social Development Goals vs Environmental Sustainability

Variable	Root 1	Root 2
<i>Left set</i>		
Goal 1 Score	0.016	0.735
Goal 2 Score	-0.157	-0.531
Goal 3 Score	1.058	0.088
Goal 5 Score	0.467	-0.215
Goal 6 Score	0.081	-0.929
Goal 7 Score	-0.326	-0.941
Goal 11 Score	-0.055	0.904
Goal 4 Score	-0.129	0.606
<i>Right set</i>		
Goal 15 Score	0.199	-0.835
Goal 14 Score	-0.167	-0.363
Goal 13 Score	-0.944	-0.291

Source: own calculations

By looking at the absolute values of the weights, we can rank the variables in each set based on the magnitude of their canonical weights for each root. The larger the absolute value, the more influential the variable is in determining the respective set (Figure 2).

Figure 2. Interinfluence among Environmental Sustainability Goals and Social Development Goals (Root 1)



Source: own research

This ranking indicates the variables' relative importance in contributing to each canonical root within their respective sets.

Social Development Goals vs Economic Development and Sustainable Growth Goals

Table 8 presents the results of a CCA. This analysis has two variables: the left set and the right set. The left set comprises eight variables, including Goal1 score, Goal2 score, Goal3 score, Goal5 score, Goal6 score, Goal7 score, Goal11 score, and Goal4 score. The right set consists of four variables: Goal8 score, Goal9 score, Goal10 score, and Goal12 score.

Table 8. Canonical Analysis Summary Social Development Goals vs Economic Development and Sustainable Growth Goals

	Left Set	Right Set
No. of variables	8	4
Variance extracted	88.12%	100%
Total redundancy	65.6%	59.67%
Variables: 1	Goal 1 Score	Goal 8 Score
2	Goal 2 Score	Goal 9 Score
3	Goal 3 Score	Goal 10 Score
4	Goal 5 Score	Goal 12 Score
5	Goal 6 Score	
6	Goal 7 Score	
7	Goal 11 Score	
8	Goal 4 Score	

Source: own calculations

The Canonical R-value, which measures the strength of the relationship between the two sets of

variables, is 0,93, indicating a strong correlation between the left and right sets. The Chi-square test statistic, with 32 degrees of freedom, is 281.17, with a p-value of 0.0, suggesting that the relationship between the sets of variables is statistically significant. In the left set, 88.1215% of the variance is extracted, and the total redundancy is 65.5853%. In the right set, 100% of the variance is extracted, and the total redundancy is 59.67%.

In this analysis, Root 1 (Table 9) displays the highest eigenvalue, indicating that it accounts for the greatest variance among the SDG Scores. In contrast, Root 3 has the smallest eigenvalue, which implies that it explains the least variance.

Table 9. Eigenvalues for canonical roots Social Development Goals vs Economic Development and Sustainable Growth Goals

Root	Eigenvalues (SDG Scores)			
	Root 1	Root 2	Root 3	Root 4
Value	0.862666	0.393007	0.274326	0.020343

Source: own calculations

Table 10 details the results from Chi-Square Tests with successive roots removed from the CCA. The canonical correlation (R) for the first root is approximately 0.717, showcasing a significant relationship between the variables in the canonical variate. The canonical R-square value is 0.514, meaning the predictors explain 514% of the variance. This model is supported by a chi-square statistic of 84.214 with 24 degrees of freedom, resulting in a highly significant p-value and confirming the statistical significance of the model.

Table 10. Chi-Square Tests with Successive Roots Removed Social Development Goals vs Economic Development and Sustainable Growth Goals

Root Removed	Chi-Square Tests with Successive Roots Removed (SDGs Scores)					
	Canonical R	Canonical R-sqr.	Chi-sqr.	df	p	Lambda Prime
0	0.928798	0.862666	281.1653	32	0.000000	0.059262
1	0.626903	0.393007	83.6243	21	0.000000	0.431519
2	0.523761	0.274326	33.9500	12	0.000690	0.710912
3	0.142629	0.020343	2.0450	5	0.842881	0.979657

Source: own calculations

Furthermore, the proportions of variance extracted by the roots (Table 11) suggest that Root 1 is pivotal in explaining variance within the left set of SDG scores. Table 11 shows that a high variance extracted (0.703275) and a high redundancy (0.606691) for the left set suggest that the first canonical variable captures a significant part of the variability in the left set. Roots 2, 3, and 4 for the left set show a sharp decline in variance extracted and redundancy. This indicates that subsequent roots contribute less to explaining the variance and shared information between the two sets. Especially for Root 4, the extremely low redundancy (0.000690) suggests almost negligible shared information with the right set.

Similar to the left set's first root, the right set shows a strong explanatory power (0.604519 in variance extracted) and a notable amount of shared information (0.521498 in redundancy) with the left set. As with the left set, roots 2, 3, and 4 have a significant drop in variance extracted and redundancy values. Root 3, however, shows a relatively higher variance extracted (0.166371) than Root 2, but still has moderate redundancy. Root 4, much like in the left set, has very low redundancy, indicating minimal shared information.

Table 11. Variance Extracted (Proportions) Social Development Goals vs Economic Development and Sustainable Growth Goals

Root/Factor	Variance extracted	Redundancy
<i>Left set</i>		
Root 1	0.703275	0.606691
Root 2	0.075504	0.029674
Root 3	0.068525	0.018798
Root 4	0.033911	0.000690
<i>Right set</i>		
Root 1	0.604519	0.521498
Root 2	0.066839	0.026268
Root 3	0.166371	0.045640
Root 4	0.162271	0.003301

Source: own calculations

Table 12 presents the factor structure for the left set of variables (SDG Scores) across four roots in the analysis of Social Development Goals versus Economic Development and Sustainable Growth Goals. The factor loadings for Root 1 are predominantly high and positive for all the goals, notably for Goals3 & 4, which have the strongest loadings, indicating that Root 1 captures a significant and positive influence on these SDG Scores in canonical variation. This suggests that the first root embodies a core dimension that strongly represents a common underlying factor that drives performance in the right set. This analysis highlights that while Root 1 is crucial for understanding the primary driving forces behind SDGs in the right set, the other roots contribute increasingly complex and less dominant patterns of influence.

Table 12. Factor Structure Left Set Social Development Goals vs Economic Development and Sustainable Growth Goals

Root Variable	Factor Structure, left set (SDGs Scores)			
	Root 1	Root 2	Root 3	Root 4
Goal 1 Score	0.822322	0.313787	-0.335740	0.033321
Goal 2 Score	0.648965	0.536786	0.475336	-0.054647
Goal 3 Score	0.958001	0.004369	-0.271701	-0.031833
Goal 5 Score	0.817016	-0.412070	0.316777	-0.005172
Goal 6 Score	0.858795	0.050733	0.111345	0.411255
Goal 7 Score	0.834849	-0.091121	-0.146830	-0.108055
Goal 11 Score	0.857519	-0.179698	-0.037198	-0.052009
Goal 4 Score	0.879609	0.066661	0.005249	-0.287468

Source: own calculations

Table 13 displays the factor structure for the right set of SDG Scores related to Social Development Goals versus Economic Development and Sustainable Growth Goals, spanning four roots. Here, Root 1 again stands out with strong positive loadings for Goals8 & 9, indicating a predominant influence of this root on these goals, particularly Goal9, which nearly reaches a loading of 1. This suggests that the primary canonical variable powerfully and positively impacts the performance and dynamics of the left set. Conversely, Goal10 shows a moderate positive relationship with Root 1, but displays significantly negative loading in Root 3, suggesting complex interactions with other factors.

Table 13. Factor Structure Right Set Social Development Goals vs Economic Development and Sustainable Growth Goals

	Factor Structure. right set (SDGs Scores)			
	Root 1	Root 2	Root 3	Root 4
Goal 8 Score	0.793197	0.115918	0.453018	0.390098
Goal 9 Score	0.972527	0.140991	-0.184529	-0.016199
Goal 10 Score	0.329090	0.369948	-0.588775	0.638891
Goal 12 Score	-0.857208	0.311735	0.282050	-0.297429

Source: own calculations

Overall, the Canonical Analysis indicates a strong relationship between the sets of variables, suggesting that changes in one set are associated with changes in the other. At the same time, the canonical weights of variables in each set (Table 14) indicate how much each variable contributes to the relationship between the two sets of variables. Table 14, presenting the canonical weights for the Social Development Goals versus Economic Development and Sustainable Growth Goals, reveals a nuanced relationship between various goals in both the left and right sets under Root 1. In the left set, Goal3 has the highest positive weight (0.601), suggesting it has the strongest positive influence on the canonical variable, making it a key driver in this relationship. Goals2 & 5 also exhibit positive weights, although to a lesser extent. Conversely, Goals1, 7, 10 & 12 in the right set display negative weights, indicating an inverse relationship with the canonical variable. Particularly in the right set, Goal9 stands out with a very high positive weight (0.765), emphasizing its significant role. The negative weights for Goals10 & 12 in the right set suggest that improvements in these goals might be inversely related to the canonical variable, potentially indicating trade-offs or conflicting objectives between these specific goals and others within the model. This analysis highlights the complex interplay and varying degrees of influence that different SDGs have on each other within this canonical framework.

Table 14. Canonical Weights Social Development Goals vs Economic Development and Sustainable Growth Goals

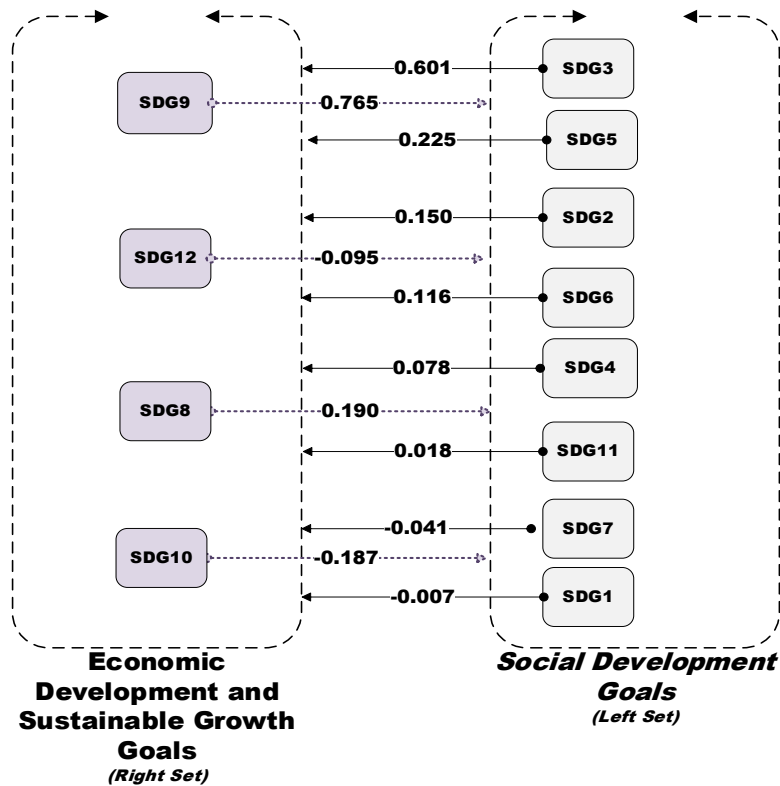
	Root 1
Goal 1 Score	-0.007
Goal 2 Score	0.150
Goal 3 Score	0.601
Goal 5 Score	0.225
Goal 6 Score	0.116
Goal 7 Score	-0.041
Goal 11 Score	0.018
Goal 4 Score	0.078
Goal 8 Score	0.190
Goal 9 Score	0.765
Goal 10 Score	-0.187
Goal 12 Score	-0.195

Source: own calculations

By examining the absolute values of the weights, we can determine the influence of each variable within each set by ranking them according to the magnitude of their canonical weights for

each root. Variables with larger absolute values have a greater impact on shaping their respective sets (Figure 3).

Figure 3. Interinfluence among Social Development Goals and Economic Development and Sustainable Growth Goals (Root 1)



Source: own research

6. DISCUSSION

The analysis of SDGs through Canonical Correlation Analysis (CCA) presents a compelling insight into the complex interrelationships among these goals, as evidenced by the correlation heatmap and factor structures. The heatmap reveals both synergistic and antagonistic interactions among the SDGs. For instance, several goals demonstrate strong positive correlations, suggesting that progress in one area could facilitate improvements in others, indicative of synergistic effects that could be leveraged to enhance overall sustainable development. Conversely, negative correlations highlight potential trade-offs, where advancements in specific goals might impede progress in others, necessitating careful consideration in policy formulation and implementation to mitigate adverse impacts.

The theoretical framework categorizes the SDGs into distinct groups – Social Development Goals, Environmental Sustainability Goals, and Economic Development and Sustainable Growth Goals – each reflecting a unique facet of sustainable development but interconnected in complex ways. The detailed canonical analysis between these groups, particularly the Social Development Goals and Environmental Sustainability Goals, emphasizes the need for an integrated approach in planning and strategy development. This integration is crucial, as shown by the significant canonical correlations and variance explained, underscoring those achievements or failures in one category profoundly impact the others. For instance, SDG 7's focus on sustainable energy is portrayed as an infrastructure goal and a driver of societal well-being, education, and economic equality, highlighting the interconnectedness and multi-faceted impacts of these goals.

Based on the comprehensive analysis of the interdependencies among the Sustainable Development Goals (SDGs) and the insights derived from Canonical Correlation Analysis (CCA), here are specific strategies and guidelines for policymakers to effectively address these relationships:

1. Encourage the creation of policies that simultaneously address multiple SDGs. Policymakers should design initiatives that recognize and leverage synergies, such as linking energy access (SDG7) with health outcomes (SDG3) and education (SDG4) – integrated policy development.
2. Utilize the empirical insights gained from CCA to inform policy decisions. Establish a framework for using SDG scores and correlation data to guide resource allocation and strategic planning – evidence-based decision making.
3. Foster collaboration across different sectors and government departments to ensure that strategies are aligned. For instance, energy policies should involve health, education, and economic sectors to maximize positive impacts – cross-sector collaboration.
4. Develop a robust monitoring system that tracks progress across interconnected SDGs. Utilize standardized metrics to evaluate the effectiveness of policies, allowing for adjustments based on empirical data – evaluation framework.
5. Invest in training programs for policymakers and stakeholders to enhance their understanding of the interdependencies among SDGs. This can include workshops on statistical methods like CCA to interpret data effectively – capacity building and training.
6. Involve local communities, NGOs, and private sector partners in the policymaking process. Their input can provide valuable perspectives on how policies may affect various SDGs and help identify potential trade-offs – stakeholder engagement.
7. Launch awareness initiatives that educate the public on the interconnected nature of the SDGs. Informed citizens can advocate for cohesive policies and hold leaders accountable for integrated approaches – public awareness campaigns.
8. Prioritize funding and resources for initiatives that have the potential to impact multiple SDGs positively. For example, investments in renewable energy not only support economic growth (SDG8) but also contribute to climate action (SDG13) and improved health (SDG3) – resource allocation strategies.
9. Recognize and address potential trade-offs among SDGs. Implement strategies that mitigate negative impacts, such as policies that balance economic growth with environmental sustainability – focus on trade-offs.
10. Encourage a long-term perspective in development planning that anticipates future interdependencies and challenges. This can include scenario planning and modeling to understand potential outcomes of policy decisions – long-term visioning.

By adopting these strategies, policymakers can create more cohesive, effective, and sustainable development initiatives that acknowledge and harness the complex dynamics of interdependencies among the SDGs.

7. CONCLUSIONS

Based on the analysis, Goal3 (Health and Well-being) and Goal5 (Gender Equality) are the most influential Social Development Goals impacting the Economic Development and Sustainable Growth Goals. Their influence is likely mediated by the ways improvements in health and gender equality enhance economic productivity, create more stable and inclusive work environments, and facilitate broader societal benefits that underpin sustainable economic growth. To further refine and validate these conclusions, a detailed examination of specific interactions between these goals and additional empirical research could be beneficial. This would enhance

understanding of these social goals' direct and indirect effects on economic outcomes, aiding in more targeted and effective policymaking.

Based on the analysis, Goal6 (Clean Water and Sanitation), Goal7 (Affordable and Clean Energy), and Goal11 (Sustainable Cities and Communities) emerge as the most influential Social Development Goals affecting the Environmental Sustainability Goals. These goals directly interact with environmental management and conservation practices, making them pivotal in achieving sustainability objectives. They address core elements of environmental sustainability, such as resource efficiency, pollution reduction, and sustainable urbanization, which are essential for maintaining ecological balance and ensuring long-term environmental health. Further analysis and focused studies could deepen the understanding of these interactions, providing a more nuanced view of how specific policies and initiatives within these goals can enhance environmental sustainability efforts.

The statistical significance and the patterns of association revealed through the CCA provide a quantitative foundation for policymakers to prioritize and strategize SDG efforts. The analysis suggests that while some goals may be more influential or central in their impact, others may require more nuanced interventions to avoid unintended consequences. Future studies should investigate these goals' causal relationships and potentially conflicting objectives to inform sustainable development strategies better. Additionally, extending this analysis to include more granular data and exploring the dynamic changes over time could further enhance the understanding and effectiveness of SDG implementations. The ultimate aim should be to foster policies that advance individual goals and harmonize the broader objectives of sustainable development.

To effectively address these interdependencies, policymakers are urged to adopt integrated approaches that consider the holistic nature of sustainable development. This includes the formulation of evidence-based policies, fostering cross-sector collaboration, and engaging stakeholders to create synergies while managing trade-offs. By leveraging empirical insights from the analysis, a comprehensive and cohesive framework can be developed to guide sustainable development efforts, ensuring that advancements in one goal do not come at the expense of another, ultimately driving a more sustainable and equitable future.

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