“Analyzing Synergies and Trade-offs within and between Sustainable Development Goals: A Global Perspective through the lens of Human Development Index”

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Submitted by:
Varun (20191190)
Supervisor:
Dr. Bejoy K Thomas
Associate Professor
IISER-Pune

Co-Supervisor:
Dr Tulasi Ram Annapareddy
VP
Barclays , Noida

Declaration

I hereby declare that the matter embodied in the report entitled "Analyzing Synergies and Trade-offs within and between Sustainable Development Goals: A Global Perspective through the lens of Human Development Index" is the results of the work carried out by me at the Department of Humanities and Social Science , Indian Institute of Science Education and Research (IISER) Pune, under the supervision of Dr. Bejoy K Thomas & Dr. Tulasi Ram Reddy Annapareddy and the same has not been submitted elsewhere for any other degree. Wherever others contribute, every effort is made to indicate this clearly, with due reference to the literature and acknowledgment of collaborative research and discussions.

Varun

20191190

Certificate

This is to certify that this dissertation entitled **"Analyzing Synergies and Trade-offs within and between Sustainable Development Goals: A Global Perspective through the lens of Human Development Index"** submitted towards the partial fulfillment of the BS-MS degree at the Indian Institute of Science Education and Research, Pune, represents original research carried out by Varun at the Indian Institute of Science Education and Research (IISER) Pune, under the supervision of **Dr. Bejoy K Thomas & Dr. Tulasi Ram Reddy Annapareddy**, during the academic year May 2023 to March 2024.

Supervisors:

Dr. Bejoy K Thomas

Associate Professor,IISER-Pune

Dr. Tulasi Ram Annapareddy

VP ,Barclays, Noida

Varun

20191190

BS-MS

IISER Pune

In memory of my Father

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Abstract

The United Nations' 2030 Agenda for Sustainable Development, which includes 17 Sustainable Development Goals (SDGs), serves as a comprehensive and integrated roadmap for addressing global economic, social, and environmental concerns. However, the complex interdependence of these diverse goals necessitates a comprehensive knowledge of the synergies and trade-offs that support their collective pursuit. This study extends earlier assessments by including an additional 6-7 years of data through 2022, allowing for a re-evaluation of SDG progress trajectories and the detection of emergent patterns.This study also broadens the longitudinal scope by employing advanced correlation techniques to capture non-linearity. It uses the HDI as a multidimensional lens, all of which contribute to a better understanding of the complex processes that support sustainable development. The findings show significant levels of synergy among SDGs such as 3 (Health), 5 (Gender), 6 (Water), 7 (Energy), and 9 (Industry/Innovation), with SDG 3 showing as particularly catalytic across the framework. Trade-offs focus on SDGs 2 (Hunger) and 9. When viewed via the HDI lens, there is significant variation: SDG 15 (Life on Land) has more synergy in high HDI nations, whereas SDG 3 priorities are aligned with poor HDI environments. Identifying context-specific SDG interlinkages can help guide transformative policymaking that capitalizes on synergies and controls tradeoffs through deliberate, coordinated actions. However, data gaps and methodological restrictions prevent SDG linkages from being completely characterized across the whole development spectrum. Nonetheless, this study's multi-pronged analytical methodology provides a blueprint for attaining Agenda 2030's holistic goal through systematic cross-sectoral collaboration.

Contents

1 Introduction

1.1 what are SDGs?

An important turning point in the history of global cooperation occurred during the Earth Summit in Rio de Janeiro, Brazil, in June 1992. At this gathering, delegates from more than 178 countries adopted Agenda 21, a comprehensive plan to promote an international coalition for sustainable development. This all-encompassing action plan outlined methods to improve human welfare while protecting the environment and was supported by major groups, national governments, and UN organizations. Agenda 21 called for concerted efforts at the local, national, and international levels to lessen the effects of human activity on the environment.

In September 2000, the United Nations Millennium Summit met at its New York headquarters. At this point, Member States unanimously adopted the Millennium Declaration, laying the groundwork for developing eight Millennium Development Goals (MDGs). These targets covered a wide range of objectives, from alleviating extreme poverty to ending the HIV/AIDS epidemic and achieving universal primary education. The MDGs were a collaborative blueprint universally embraced by nations and leading development institutions, propelling unprecedented efforts to address the needs of the world's poorest populations.

As the 2015 deadline approached, the global community sought to capitalize on the momentum created by the MDGs. Beginning in January 2015, world leaders around the globe started negotiating a successor to the MDGs. This process culminated in September 2015 at the UN Sustainable Development Summit when the international community adopted the 2030 Agenda for Sustainable Development., marking a key milestone in sustainable development for developing and developed countries. The concept of SDGs was designed in a way that it encompasses all changes after the 2015 MDGs. This initiative was more directed towards holistic and sustainable development. The 'leaving no one behind' tagline and the concepts of universality, inclusion, and integrality—all of which were absent from the MDGs (Millennium Development Goals and Agenda 21)—form the foundation of the 2030 Agenda. Thus, the UN presents the 2030 Agenda, which seeks to enhance human well-being, economic advancement, and environmental protection in order to improve living conditions worldwide..

The Sustainable Development Goals (SDGs) are a set of 17 major objectives established by the United Nations in 2015 to drive global sustainability efforts across economic, social, and environmental dimensions. These overarching goals encompass critical issues such as poverty alleviation, affordable clean energy, decent work conditions, and climate action. For example, SDG 1 is concerned with poverty eradication, whereas SDG 6 is concerned with guaranteeing universal access to safe drinking water and sanitation. Similarly, SDG 15 is concerned with the protection and sustainable use of terrestrial ecosystems. while SDG 3 accounts for Good health and well-being. Under the umbrella of these 17 goals are further articulated 169 specific targets that outline tangible milestones towards each goal. For example, in SDG 2 (Zero Hunger), target 2.2 aims to eliminate all types of malnutrition by 2025, including meeting internationally agreed-upon targets for stunting and wasting in children under five. Similarly, SDG 6 (Clean Water and Sanitation) encompasses target 6.3, which aims to enhance water quality by decreasing pollution, eliminating dumping, and preventing the release of dangerous chemicals and materials.

To track progress towards these 169 targets, the UN has delineated 232 measurable indicators. These indicators are quantitative observable and provide standardized metrics to assess advancement over time, such as 2.2.1, which monitors the prevalence of stunting in children under the age of five, and indicator 3.2.1, which measures the under-5 death rate. Similarly, in SDG 14 (Life Below Water), indicator 14.2.2 measures the proportion of biologically viable fish stocks. This sophisticated hierarchy of goals, targets, and indicators exemplifies a systematic approach to thoroughly addressing multifaceted difficulties, thus paving a systematic pathway for global sustainable development activities.

1.2 Why are sdgs important ?

This hierarchical framework of SDGs compromising 17 Goals 169 targets and 232 indicators improves on the success of previous target and indicator-based frameworks, one of them being Millennium Development Goals (MDGs)(Caballero 2019,McArthur and Rasmussen 2018 , Helgason 2016). It aims to resolve the delayed progress made on major international environmental agreements. As compared to it's predecessors SDGs give a overall better coverage and balance on sustainable development's economic, social, and environmental fronts and the opportunity to stimulate a systemic sustainable change moving into the future (Costanza et al. 2016).

The Sustainable Development Goals (SDGs) have a worldwide impact, and their indivisible nature needs a comprehensive strategy that goes beyond traditional boundaries. The 2030 Agenda for Sustainable Development necessitates a shift in paradigms, breaking down conceptual, sectoral, and institutional barriers. It advocates for executing the SDGs and their associated targets as an interconnected system, with one aspect influencing and being influenced by others, resulting in a network of multidimensional, cascading, and sometimes reciprocal consequences. This holistic approach recognizes the complicated relationships between diverse areas of sustainable development, necessitating a united and integrated strategy to attain desired goals. Significantly, this approach favors innovative ideas that achieve sustainable development while engaging a Benefitting a diverse range of individuals via an inclusive, interdisciplinary method that respects diverse cultural backgrounds and expertise. (Tremblay et al. 2020,Villeneuve et al. 2015) This interdependent set of economic, social, and environmental objectives recognizes that progress in one area often depends on and impacts advancement in others. Therefore, the crux of effectively implementing the SDGs is comprehensively mapping the synergies and trade-offs between goals and targets. Quantitatively analyzing the layered interactions and dependencies within the framework is essential to optimize across sectors, inform integrated policymaking, and achieve the holistic vision for 2030. Identifying interconnections between the many SDG targets is a massive task, given the expansive scope of the goals' framework. Only a few authors have attempted to map or define relationships between SDGs and their aims systematically.(Tremblay et al. 2020) surveyed people to classify SDG targets across the five pillars of sustainable development(People, Planet, Prosperity, Peace, and Partnership). They scored target similarities and tested if these related to positive or negative interactions. Nevertheless, surveying people to classify SDG targets across pillars of sustainability provides limited insight into systemic interactions between goals. This is because many SDGs demonstrate significant interdependencies; previous research has identified particularly strong connections and externalities between specific goals. Therefore, actively checking linkages within and across SDG goals can provide deeper insights and progress toward fulfilling the 2030 Agenda.

The interdependence between varying Sustainable Development Goals (SDGs) is well-established. Studies demonstrate the highly interconnected nature of SDGs, whereby progress in one goal impacts outcomes in others. The progress and achievement of the SDGs in the future will depend on whether the synergies and cross-sectoral and cross-goal cooperative relations between SDGs are fostered. SDGs should be treated as a system of interacting cogwheels that move with the academic research work policies promoting cross-sectoral and supportive policies (Pakkan et al. 2023).SDG relations have to be instigated to ensure the successful implementation of the SDG indicators in the future. (Tosun and Leininger 2017) differentiate between two forms of Sustainable Development Goals (SDGs) interconnections: intersectoral and multisectoral. linkages. intersectoral linkages suggest that the SDGs are mutually influential and must be achieved in tandem. In contrast, multisectoral linkages indicate that the SDGs must be realized collectively. Furthermore, they propose two distinct strategies for policy coherence: substantive and procedural. Substantive strategies necessitate modifying the policy content and the associated institutional structures. Procedural strategies, on the other hand, require alterations solely to the policy process. The choice of policy coherence approach can vary across countries, depending on the level of SDGs integration, domestic policy-making procedures, and institutional implementation arrangements. Therefore, comprehending these interlinkages is vital for enhancing policy implications and thus puts SDGs at the nexus for sustainable policy-making for everyone's being. For example, SDG 3 (Good Health and Well-Being) demonstrates substantial synergies with SDGs 1, 6, 7, and 12(Pradhan et al. 2017). .

These interdependencies manifest clearly between individual SDG pairs and within an individual SDG group. For example, success in SDG 3 on health intrinsically links to SDG 1 on poverty, as poor health drives medical impoverishment. Similarly, hunger (SDG 2) undermines educational outcomes (SDG 4), while quality education empowers healthier behaviors. Environmental degradation (SDGs 12-15) can destroy livelihoods, undercutting poverty alleviation (Pradhan et al. 2017; Lusseau and Mancini 2019). Thus, while studying a particular SDG, looking for synergies and tradeoffs between different goals is essential, as interactions can either propel or hinder overall progress. A comprehensive understanding of these interdependencies is essential for implementing integrated approaches to optimize across targets(Pradhan et al. (2017)). Previous studies have employed diverse methodologies to characterize interactions between the SDGs.(Pradhan et al. 2017) Utilized nonparametric Spearman's rank correlation test to assess the synergies and tradeoffs between all possible combinations of the indicator data pairs globally . (Lusseau and Mancini 2019) utilized linear mixed effects models to assess associations between indicator pairs, with the country as a random effect and autoregressive lag structures. They disaggregated analyses by income level using GDP per capita as a control. Warchold, Pradhan, and Kropp 2021 leveraged multiple correlation techniques, including the maximal information coefficient, to categorize synergies, trade-offs, and linear/nonlinear relationships between goals. They also disaggregated their classification by income, population, and geography. Meanwhile,(Ament et al. 2020) applied linear and generalized additive models for more extended time series to capture potential nonlinearities. They also used ordinary least squares regression to delineate income-based dependencies.

These analyses revealed complex dynamics between the SDGs that vary dramatically across socioeconomic strata. (Lusseau and Mancini 2019) Specific goals emerge as critical priorities within the SDG framework for different income levels, with SDG 1 (No Poverty) and SDG 10 (Reduced Inequalities) structuring low- and high-income country networks, respectively. They also identified SDGs 12 and 13 as major obstacles across income levels. (Warchold, Pradhan, and Kropp 2021) determined that SDGs 1, 5, and 6 exhibited predominantly synergistic interactions, while SDGs 2, 5, and 17 participated in more trade-offs. They observed the highest share of synergies between SDGs 3 and 7 and considerable nonlinear trade-offs between SDGs 3 and 12. (Mejía-Guevara et al. 2019) Focus specifically on forecasting progress towards SDG 3.2 (reducing under-5 mortality to 25 per 1,000 live births by 2030). Using full birth history data from 31 sub-Saharan African countries, they model age-specific under-5 mortality rates from 1990-2017 and forecast rates to 2030 and 2050. Their model reveals that only five countries are on track to meet the 2030 SDG target based on current trends, with neonatal mortality declining slower than under-5 mortality across the region. (Subramanian et al. 2023) assess progress towards SDG indicators spanning poverty, health, gender equality, hunger, water, sanitation, and energy access at the sub-national level in India. Using data from two rounds of the National Family Health Survey in 2016 and 2021, they estimate annual absolute change across 33 SDG indicators for 707 districts. Their analysis categorizes districts as on target, off target, or achieved based on linear projected trajectories. Only 5 of 33 indicators have over 75 % of districts on target, pointing to significant gaps in progress on poverty, nutrition, health, and gender equality goals.

Linear Monotonic associations like spearmen correlation (Pradhan et al. 2017) and the five pillar system (Tremblay et al. 2020) may not adequately capture all the intricate relationships and dependencies among various SDGs, limiting the depth of our understanding of sustainable development dynamics. (Warchold, Pradhan, and Kropp 2021) leveraged multiple correlation techniques, including the maximal information coefficient, to categorize synergies, trade-offs, and linear/nonlinear relationships between goals. MIC is particularly effective in revealing monotonic and non-monotonic dependencies between indicator time series, providing a more nuanced view of SDG interactions. While it can be used as a metric for exploring large datasets and detecting non-monotonic associations between tens of thousands of variable pairs, it has some limitations. One limitation is that its heuristic estimator, APPROX-MIC, is computationally demanding, making it challenging to apply to large datasets. Another limitation of MIC could be the directionality and type of relationship, as MIC is unidirectional and does not report the direction of the relationship.

To address the computational challenges associated with the maximal information coefficient (MIC) and the unidirectional nature of its relationships, a promising alternative correlation matrix could be the ξ correlation. The ξ correlation builds on the qualities of the Spearman correlation and the MIC while resolving their shortcomings. Instead of the Spearman correlation, the Xi(ξ) correlation captures linear and nonlinear linkages, fully understanding the numerous relationships within the Sustainable Development Goals (SDGs). Previous efforts in mapping SDG interactions relied heavily on linear associations with Gross Domestic Product (GDP), oversimplifying inherent complexities (Lusseau and Mancini 2019).In mapping interactions among Sustainable Development Goals (SDGs), the Human Development Index (HDI)(Anand and Sen 1994; Ogwang 2000;Kelley 1991) could be a better indicator of progress than GDP because, Unlike other more complicated indices, it displays a more nuanced grasp of human growth while yet being reasonably straightforward.The three indices that make up the HDI framework are the Income Index, which accounts for inflation and exchange rate adjustments when determining an individual's wealth, the Education Index, and the Life Expectancy Index. The Human Development Index (HDI) monitors human development which focuses on qualitative advancement components, as opposed to GDP, which measures a person's living level. Additionally, the Human Development Index (HDI) will be more effective than GDP in capturing the progress made over a 15-year period. (Lashmar 2018).

The Sustainable Development Goals (SDGs) are a comprehensive and linked framework for solving global development concerns on economic, social, and environmental levels. progress towards the SDGs is highly interrelated, with synergies and tradeoffs across targets that must be recognized and managed to fulfill the 2030 Agenda. Quantifying the complex interlinkages between Sustainable Development Goals (SDGs) demands methodologies to capture nonlinear relationships and feedback loops within the framework. Techniques such as the maximal information coefficient (MIC) and Xi(ξ) correlation can elucidate intricate dependencies that traditional linear correlation analyses miss. These nonlinear associations better reflect targets' reciprocal and reinforcing nature across economic, social, and environmental factors. Furthermore, categorizing countries by multidimensional yardsticks, including the Human Development Index (HDI) rather than gross domestic product(GDP), enables more nuanced evaluations of sustainable development pathways. Stratifying development-level analyses characterizes variability in SDG priorities and progress across global income strata. A sophisticated understanding of synergies and tradeoffs within and between goals can ultimately inform integrated policymaking. Systemic approaches that spur cross-sectoral cooperation and target multiply reinforcing interventions will prove critical for realizing Agenda 2030. A complex systems perspective of SDG linkages, advanced analytical techniques, and multidimensional assessments provide a roadmap for transformative change.

2 Methodology

The Inter-Agency and Expert Group on Sustainable Development Goal (SDG) Indicators developed a comprehensive list of indicators endorsed by the United Nations Economic and Social Council in 2015 to track SDG progress. It is important to note that the United Nations Statistics Division has made data for 244 of these variables(out of which there are 235 unique indicators) available as of 2023, covering a total of 273 countries for the period from 1983 to 2023.

The data for these Sustainable Development Goal (SDG) indicators were sourced from the dissemination platform of the Global SDG Indicators Database. Our analysis solely utilized numerical, national-level time series data for each indicator. Excluding potential segmentation based on income, gender, age, race, ethnicity, migratory status, disability, geographic location, or other demographic factors. The probable lack of disaggregated data across all countries influenced this decision.. Recognizing that the time series for these SDG indicators ranged in length from 1983 to 2023, with an intense concentration in the years from 2000 to 2023, the temporal scope of our study will be primarily focused on the years from 2000 to 2022. To conduct a robust analysis, we took the additional step of excluding indicators with fewer than five observations within a given time series. This data curation process ensured our analytical approach's reliability and statistical robustness(Ament et al. 2020).

This updated analysis provides a valuable opportunity to evaluate our progress toward achieving the SDGs and to identify any emerging patterns during this expanded time-frame. This study expands on the work of (Pradhan et al. 2017) by extending the analysis along two critical dimensions. First, it extends the temporal scope of the data analyzed through 2022, providing an additional 6-7 years of data beyond what (Pradhan et al. 2017). Examined initially. This extended timeline enables a comprehensive re-assessment of (Pradhan et al. 2017) conclusions regarding progress towards the Sustainable Development Goals (SDGs). It allows for identifying any new trends or trajectories that have emerged in recent years. Second, the study introduces a recently developed measure of association (ξ) proposed by Chatterjee 2020 to additionally capture any existing nonlinear relationships besides monotonic relationships.

2.1 Assesing synergies and tradeoffs

This thesis commenced by replicating the methodology employed by Pradhan et al. 2017 and applying it to an updated dataset. This replication was essential to develop a standardized approach for determining the directionality of time series data associated with each Sustainable Development Goal (SDG) indicator. By replicating this process, we aimed to ensure that this analysis was founded on sound and validated procedures, hence increasing the legitimacy and comparability of our findings to previous studies. Each time series of an indicator was assigned a sign of +1 or -1 to indicate whether an increase or decrease in the indicator's value represents progress or hindrance toward the 2030 SDG agenda (Table 1). Following this preprocessing process, the Sci-Py stats module's non-parametric Spearman rank correlation metric was used to compute the correlations between all unique indicator pairs within and across SDGs. Following a categorization framework similar to (Pradhan et al. 2017), indicator pairs with ρ values greater than +0.6 were classed as "synergies." This classification denoted a positive association, signifying that improvements in one indicator were positively correlated with changes in the other, indicating a coordinated effort to achieve the SDGs. Indicator pairings with ρ values less than -0.6 were considered "trade-offs." This classification found a negative association, suggesting that changes in one indicator were inversely related to changes in the other, implying potential conflicts or trade-offs in achieving the SDG goal.

For cases where $|\rho|$ fell below the threshold of 0.6, the indicator pairs were regarded as "non-classified" or having a "weak association." This classification indicated that the

Goal	Target	Indicator	Sign
SDG 3 (Good health and well being)	3.2 (By 2030, reduce preventable newborn deaths and children under 5 years of age)	3.2.1 (under 5 mortality)	-1
SDG 6 (Clean water and sanitization)	6.1(by 2030 achieve universal and equitable access to safe and affordable drinking water for all)	6.1.1 (proportion of population having access to clean water)	+1

Table 1: Targets and Indicators for SDGs 3 and 6

relationship between the indicators was not sufficiently strong to classify them as either synergy or trade-off in the context of SDG goals. This analytical procedure was systematically repeated within all the individual 17 SDG goals and across different SDG goals, allowing for a comprehensive assessment of synergies, trade-offs, and associations among the various indicators.

Spearman's rank correlation coefficient assesses the monotonic relationship between two variables, assuming their connection can be described solely by a monotonic function. However, this assumption oversimplifies the complex nature of relationships. To address this limitation, (Warchold, Pradhan, and Kropp 2021) proposed using MIC - R^2 to identify nonlinearities in the dataset. MIC proves robust in capturing non-monotonic relationships but demands a substantial sample size for accurate predictions. Given the challenges in obtaining a large historical SDG dataset, the low sample size remains a significant hurdle in achieving reliable insights. Additionally, Pearson's correlation coefficient is sensitive to outliers, making it less efficient in capturing monotonic relationships than Spearman's. While Spearman's correlation coefficient focuses on monotonic relationships, Chatterjee's correlation coefficient (ξ) provides a different perspective by being more sensitive to local changes (Chatterjee 2020).

Unlike traditional metrics, ξ is an asymmetric rank-based correlation with a range of 0 to 1, where values closer to 0 indicate independence and values closer to 1 show that variable X is a measurable function of variable Y. This innovative correlation metric has

correlation method	positives	negatives
Spearman(ρ)	- Can capture monotonic relationships. accurately - computationally efficient	-inefficient in detecting non-linear trends
Chatterjee (ξ)	- sensitive to local changes and detect non monotonic relationships -computationally effiecent	-conceptually more complex -erroneous for fewer data points (<10)
MIC	- robust for non linear relationships - independent for distribution assumptions	-Computationally intensive -requires large sample size
Pearson	-simple and intuitive interpretations -computationally efficient	-sensitive to outliers.

Table 2: Tradeoff table for different correlation methods

two significant advantages. Notably, Chatterjee's correlation stands out for its computational efficiency, making it suitable for extensive data analysis and functioning well with limited observations. This was one of the limitations of the MIC. Moreover, its unique ability to detect non-linear relationships distinguishes it from conventional correlation measurements. (Table 2).

(Zhang 2023) highlights instances where Spearman's correlation and Chatterjee's correlation diverge, indicating a nuanced relationship not fully captured by either metric alone. In symmetric relationships, where the correlation remains unaffected by flipping the sign of one variable, Spearman's correlation tends to be small due to the absence of a monotonic trend. However, Chatterjee's correlation is higher, emphasizing strong local changes that occur as one variable sharply increases while the other is close to zero. This discrepancy arises from the ability of Chatterjee's correlation to detect such local changes, providing a more comprehensive understanding of the relationship.(Zhang 2023) Another scenario mentioned by (Zhang 2023) involves oscillating relationships, where variables alternate between increasing and decreasing. In this case, Superman's correlation tends to be large due to a consistent monotonic trend, while Chatterjee's correlation is small, as there is no coherent local change. (Zhang 2023) underscores the importance of considering both correlation metrics, as their differences can unveil complex relationships. The analytical calculation of p-values becomes feasible when combining the two metrics under the assumption of asymptotic joint, normal, and independent behavior in cases of independence between variables. We can establish two additional categories based on comparing the two metrics. The first category involves cases where the Spearman correlation(ρ) is high and the Chatterjee correlation(ξ) is low. The second category comprises situations where the Chatterjee correlation is high and the Spearman correlation is low. These categories can be labeled as "Low ρ, High ξ", and "High ρ, Low ξ", respectively. By examining synergy and tradeoffs alongside these new categories, a more comprehensive understanding of the SDG data can be obtained, providing valuable insights into the relationships between indicators. Thus improving our ability to get more profound insights into the complicated interrelationships among SDG indicators by including the Chatterjee correlation coefficient in our analytical approach, providing a more nuanced view of the processes behind progress toward the SDG objective (Sadeghi 2022)

Recognizing the limitations of ρ in capturing non-monotonic relationships, the Chatterjee correlation The ξ correlation metric was calculated using the xicor Python package. To accomplish this, a symmetrical version of ξ, denoted by $\max(\xi(x, y), \xi(y, x))$, was computed. This symmetrical ξ computation was performed like the previous step for the given indicator pairs, x, and y, within and across the different SDGs.

The global interaction of SDG indicators are then defined as percentage of synergies, trade-offs, nonclassified, high ρ-low ξ, and high ξ-low ρ indicator pairs belonging to the same SDG between indicator or between pairs that fall within two separate goals.The outcomes resulting from the interactions between indicator pairs are then classified for each country and across the globe. Next a countrywise analysis was carried out to rank the most frequent pairs of Sustainable Development Goals (SDGs) worldwide based on the percentage of synergy and trade-offs. This global assessment only considered SDG couples with a dataset of at least 10 pairs in a country Noting large differences in the ranks of SDG pairs among countries, a frequency-based ranking system was used to determine the prevalence of specific SDG pairs among the top 10 synergistic or trade-off combinations across all nations. Some studies have attempted to map progress on the Sustainable Development Goals (SDGs) primarily in terms of economic indicators such as Gross Domestic Product (GDP) per capita (Ament et al. 2020;Lusseau and Mancini 2019). While insightful, relying solely on aggregate income measures risks oversimplifying sustainable development's complex, multidimensional nature. More holistic composite indicators like the Human Development Index (HDI) is to better capture heterogeneities in development progress by encompassing multiple aspects of human well-being as HDI captures progress in three basic dimensions of human development: health, education, and living standards, enabling cross-country comparisons similar to those provided by GDP. As such, disaggregating SDG achievement across development contexts indexed by HDI scores could reveal variability in progress patterns hidden in aggregate, GDP-based analyses. For instance, countries with similar per capita GDP but divergent health and social indicators performances may demonstrate differing SDG synergies and trade-offs. thus, filtering by HDI became critical instead of income.

To examine whether progress towards the SDGs varies across development contexts, the dataset was first stratified by each country's Human Development Index (HDI) score. Following the UNDP's classification system, four HDI groups were constituted: high HDI countries (HDI $\geq$ 0.8), high-medium HDI countries (0.7 $<$ HDI $<$ 0.8), medium HDI countries (0.5 $\leq$ HDI $\leq$ 0.7), and low HDI countries (HDI $<$ 0.5) *UNSDG* 2024.

The analytical procedure previously delineated was subsequently conducted individually within each HDI stratum. Specifically, the non-parametric Spearman's rank correlation coefficient (ρ) and the symmetrical version of Chatterjee's non-linear correlation coefficient (ξ) were computed between all unique pairings of indicators both within and across the 17 SDGs for each HDI group separately. Based on the thresholds outlined previously, these correlations were categorized as once-set categories of synergies, tradeoffs, high ρ, and low ξ, and low ρ and high ξ. Moreover, the percentage of correlation pairs falling into each categorization was calculated per HDI group. This enabled a standardized comparison of the extent of associations across high, high-medium, medium, and low HDI countries.Similarly, country-level interconnections among SDGs are calculated using the fraction of synergistic, tradeoff, and unclassified links among all indicator pairs across the country. The interactions among SDG indicators within a single goal were then quantified by determining the percentage of synergies, trade-offs, and nonclassified pairs, as well as those exhibiting high ρ-low ξ and high ξ-low ρ within each HDI group. The calculations encompassed all unique pairings of indicators within and across SDGs. Employing the predefined thresholds, the resulting correlations were classified into distinct categories, namely synergies, trade-offs, high ρ-low ξ, and low ρ-high ξ.

3 Results

This study has revealed two distinct categories of indicator pairs that warrant further investigation apart from the synergies and tradeoffs that (Pradhan et al. 2017)discusses. These categories are distinguished by their respective combinations of the Spearman correlation coefficient (ρ) and Chatterjee correlation coefficient (ξ).

The first category encompasses indicator pairs with high absolute values of ρ ($|\rho| > 0.6$) but low ξ values ($\xi < 0.2$). This combination suggests a scenario with a significant positive or negative linear association between the two indicators, as indicated by the high absolute value of ρ. However, Zhang 2023 argues that there can exist ranks $\{R_1, ..., R_n\}$ such that $\xi_n(X, Y) = \varepsilon + O(1/n)$ while $|\rho_n(X, Y)| = 1 - \sqrt{\frac{2}{27}(1-\varepsilon)^{3/2}} + O(1/n)$. in simpler terms, theoretically, there can exist a combination of indicator pairs having ξ value close to 0 and ρ value close to 1
This case is when the relationship between the variables oscillates, meaning it alternates between increasing and decreasing. The relationship oscillates if we divide the ranks into two parts, one where X and Y increase and another where X and Y decrease. Chatterjee's correlation is very small because there is no consistent local change Zhang 2023. However, Spearman's correlation is very large because there is always a strong monotonic trend: X and Y. However, given the nature of our SDG dataset (i.e., the smaller sample size for a given indicator time series), the low ξ value can possibly be low because of the smaller sample size in some indicators where values for particular indicators are close to 10 thus, strong comments are not made about this category of indicator pairs.

The second category includes indicator pairs with low absolute values of ρ but high ξ values. In this case, the low ρ value can indicate an absence of a strong linear association between the two indicators. However, the high ξ value and the low ρ value suggest a more complex and potentially non-linear relationship between the indicators.

In addition to exploring two new categories of interactions, our inquiry has extended to the examination of synergies and trade-offs. Synergistic indicator pairs are ones in which progress in one indicator correlates with progress in another. On a global scale, we need to identify synergies to identify areas where a single policy intervention has the potential to help accomplish multiple Sustainable Development Goals (SDGs). Trade-offs signify where progress in one indicator improves while another indicator declines. Policymakers must be aware of such trade-offs and carefully evaluate the priorities and potential repercussions of their actions in order to avoid unforeseen negative effects on specific SDGs while pursuing others. Naturally, this strategy has limits. The analysis does not reveal causal links that could guide investment priorities in specific countries. Context-specific analysis is necessary to produce reliable evidence. By considering these different categories of indicator interactions, policymakers can tailor their strategies and interventions accordingly. Synergies can be exploited to achieve multiple SDGs simultaneously, while trade-offs may require careful prioritization and mitigation efforts.

3.1 Interaction within SDGs

Upon examining the relationships within the Sustainable Development Goals (SDGs), it becomes apparent that various synergies and trade-offs exist across different countries*(figure 1).* Notably, SDG 3 (Good Health and Well-Being), SDG 5 (Gender Equality), SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), and SDG 9 (Industry, Innovation, and Infrastructure) exhibit a higher prevalence of synergies. SDG 3 has the most considerable synergies internationally, with almost one-third of the indicator pairings exhibiting a synergistic link. SDGs 5, 6, 7, and 9 follow closely, with one-fourth of the indicator pairings demonstrating a synergistic relationship. In contrast, SDGs 2 (Zero Hunger) and 9 have the largest trade-offs of any SDG, with about one-fifth of the indicator pairings indicating trade-offs with one another. For example, SDG 3 indicators 3.1.2 (under-five mortality) and 1.6.1 (access to key household services) exhibit synergistic relationships in over 165 countries. SDG indicators 3.1.2 and 3.2.1 appear synergistic in more countries than any other indicator, making SDG 3 the most important and impactful SDG target.

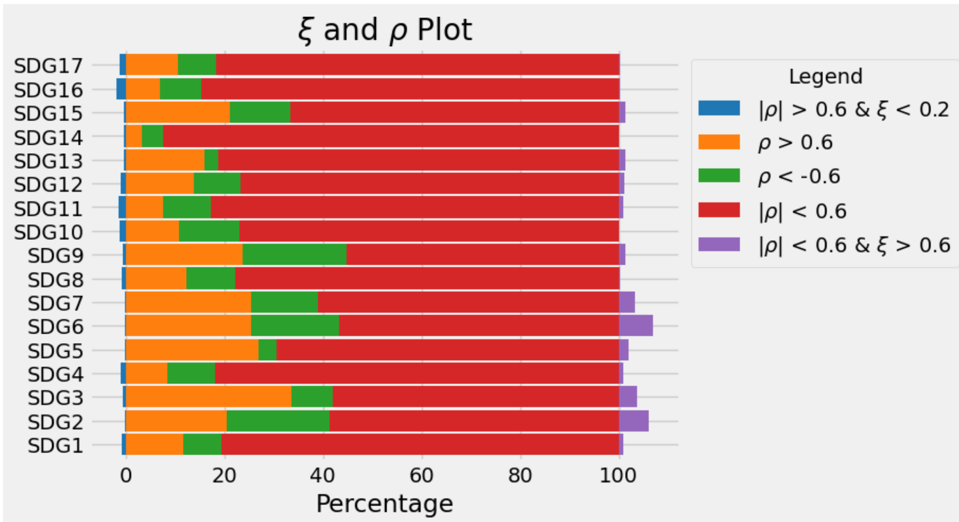


Figure 1: Synergies and tradeoffs within individual SDGs

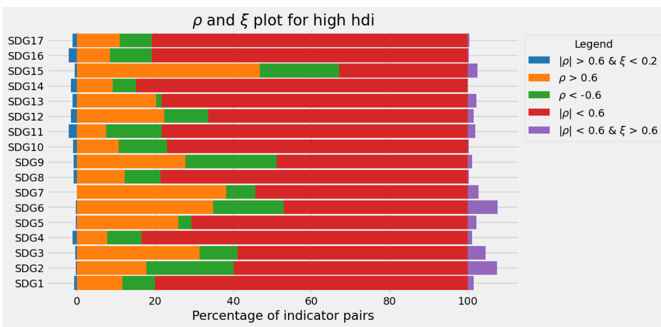
SDG 14 (Life Below Water) shows indicator pairs with ξ values below 0.2 and ρ values over 0.6. This group includes around 14 percent of all indicator pairings. However, additional examination reveals that this occurrence might be ascribed to a small sample size of observations for specific countries and should be considered outliers. For example, indicators 4.1.2 (education completion rate) and 4.5.1 (gender parity index) had ρ values above 0.6 and ξ values below 0.2. This pattern, however, is detected in only around 12 of the 248 countries, indicating that it is more of a data artifact than an underlying statistical link.

In categories with low Spearman correlation coefficients and high ξ values, we found a different pattern when ξ surpasses 0.6 and $|\rho|$ values are less than 0.6. SDG 6 (Clean Water and Sanitation) has similar relationships within this parameter range in around 7% of indicator pairs, outperforming SDG 2 (Zero Hunger), which has this pattern in about 6% of indicator pairs. Other Sustainable Development Goals (SDGs) produce limited outcomes, with percentages typically falling between 0.5 and 1 percent. However, extending the confidence interval for ξ to larger than 0.8 results in a dramatic decline in the percentage of indicator pairs showing this type of association across almost every SDG, with values hovering close to zero (0.1-0.5).

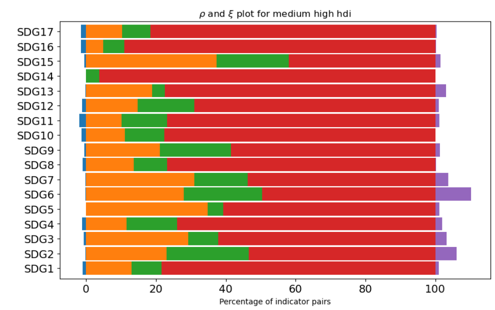
Examining sustainable development goal (SDG) relationships indicates variations in synergies and tradeoffs throughout different stages of human development *(figure2)*. In countries classed by the UN's Human Development Index (HDI), SDG 15 (Life on Land) has the most significant proportion of synergistic SDG indicator links in high and high-medium HDI contexts, with 46.8% and 37.3%, respectively. However, SDG 3 (Good Health and Well-Being) has a higher synergistic potential for medium and low HDI countries, with 40% and 43% of respective indicator pairs, respectively. However, SDG 15 (Life on Land) exhibits a nearly uniform 20-22% tradeoff rate spanning low- to high-income countries, while SDG 3 has relatively fewer tradeoffs (7-10%) across the HDI spectrum.

SDG 2 (Zero Hunger) has tradeoffs emerging uniformly across differences in human development, with 22-24% of associated indicator relationships yielding tradeoffs regardless of socioeconomic context. SDG 6 (Clean Water and Sanitation) demonstrates substantial synergies universally, with 34-38% of associated indicator pairs showing synergistic relationships regardless of a country's Human Development Index (HDI) classification. However, SDG 7 (Affordable and Clean Energy) encounters decreasing synergies while moving from highly developed to least developed nations, plummeting from 38% to 22% from high to low HDI groups.

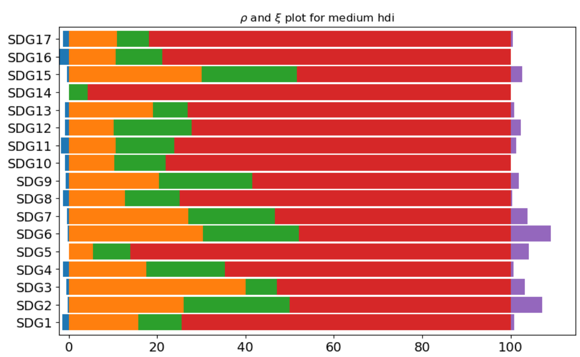
SDG 6 (Clean Water and Sanitation) encounters high tradeoffs across all development levels. However, tradeoffs gradually intensify from 18% to 25% when moving from countries with a high to a low human development index. SDG 9 (Industry, Innovation, and Infrastructure), approximately 27% of indicator pairs reveal synergies in higher Human Development Index (HDI) countries. However, this percentage declines to 17% as



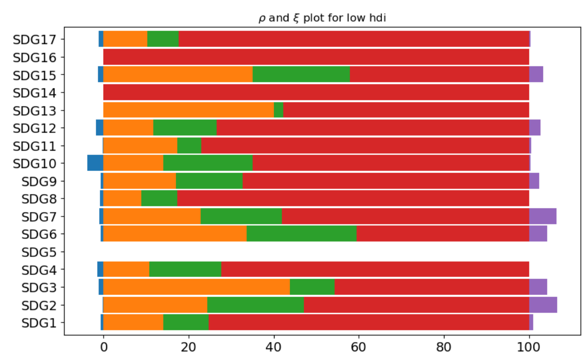
(a) Interactions within SDGs groups in high HDI (>0.8) countries



(b) Interactions within SDGs groups in medium-high HDI (0.8> HDI>0.7) countries



(c) Interactions within SDGs groups in medium-high HDI (0.7> HDI>0.5) countries



(d) Interactions within SDGs groups in LOW HDI (<0.5) countries

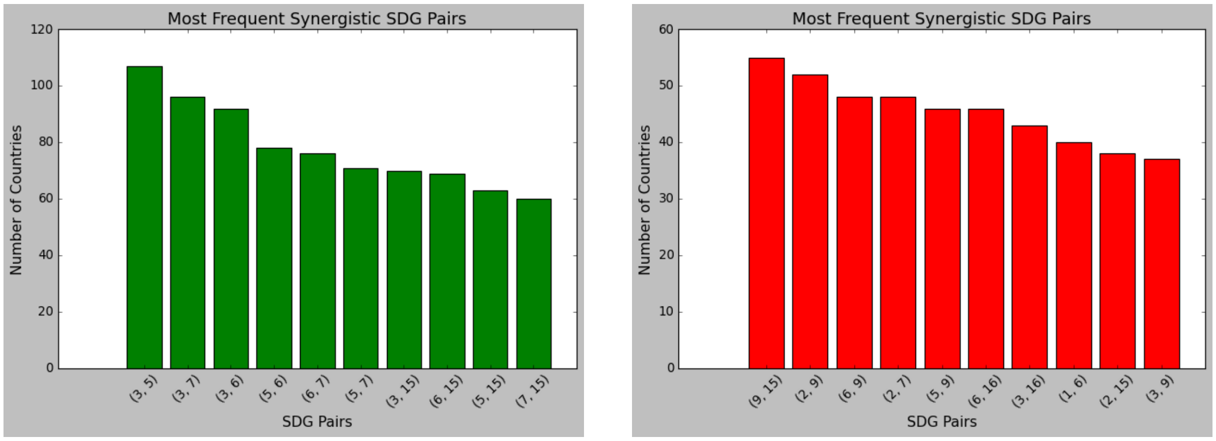
Figure 2: Comparison of interactions within different SDGs across HDI spectrum

we transition to lower HDI levels. It also encounters significant tradeoffs (around 23%) among higher HDI countries, plunging to 15% in less developed contexts. Meanwhile, SDG 10 (Reduced Inequalities) retains consistency (10-12% tradeoffs) across most HDI clusters, from a steep rise to 21% tradeoffs with countries having low HDI.

Moreover, when looking at pairs of indicators, some are notably linked with a low Spearman correlation coefficient ($\rho < 0.6$) but a high Chaterjee correlation coefficient ($\xi > 0.6$). This is especially true for Sustainable Development Goal (SDG) 2 (Zero Hunger) and SDG 6 (Clean Water and Sanitation), where 6-10% of indicator pairs show this kind of behavior, and this is consistent across the HDI spectrum. Interestingly, SDG 7 (Affordable and Clean Energy) shows an apparent increase in these pairs from highly developed to less developed nations, going from 2.3% to 7.4%. However, the differences become less noticeable when focusing on more confident pairs ($\xi > 0.8$). This suggests that while there are patterns, they might not be as robust when considering higher confidence levels.

3.2 Interactions across SDGs

Analyzing relationships across the Sustainable Development Goals (SDGs) (Fig.4 & Fig 5a) shows synergies and trade-offs exist across various countries. Notably, SDGs 3, 2, 5, 7, and 9 exhibit a higher prevalence of synergies with other SDGs and offer more synergistic opportunities. SDGs 2, 8, 9, 10, and 15, on the other hand, reveal trade-offs, indicating that progress toward one of these goals may come at the expense of others. This emphasizes the importance of carefully balancing SDG-related policies and interventions. SDG 3, which pertains to good health and well-being, displays strong synergistic relationships in over 165 countries and appears in most countries' top 10 synergy lists (Fig. 3). Specifically, indicator 3.1.2, focusing on under-5 mortality, exhibits synergies with various other indicators, notably 1.6.1, which measures access to the population with essential household services. The relationship between indicators 3.1.2 and 3.2.1 is particularly noteworthy, as it appears more synergistic than any other indicator pair.

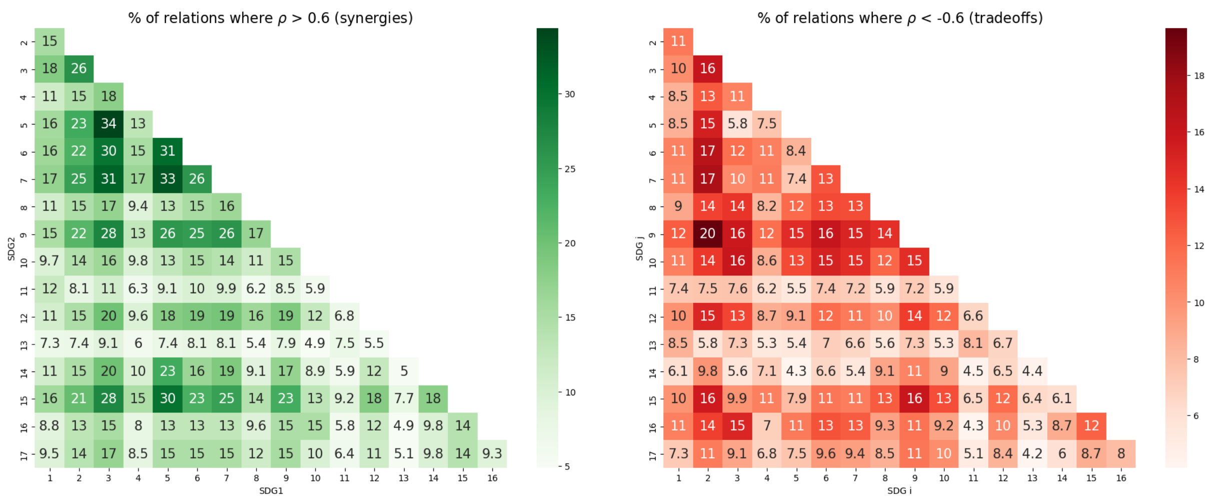


(a) most frequent synergies pairs globally (b) most frequent Trade-offs pairs globally

Figure 3: top 10 synergies and tradeoffs pairs globally

A noteworthy observation is the high synergy between SDG 3 and SDG 5. Approximately 34% of the indicator pairs between these two SDGs exhibit a synergistic relationship. The indicators 3.1.1 (Maternal mortality ratio) and 5.5.1 (Proportion of seats held by women in national-level government positions) show a synergistic relationship in over 130 countries. Similarly, indicators 3.3.2 (incidence of tuberculosis per 100,000 population) and 5.5.1 (Proportion of seats held by women in national-level government positions) are synergistic in about 140 countries. SDG 3 (Good Health and Well-being) also synergizes strongly with SDGs 15, 6, and 9. Specifically, SDG 3, as measured by Indicator 3.2.1 (under 5 mortality rate), shows synergistic relationships with SDG 15.1.2 (Average proportion of Freshwater Key Biodiversity Areas) in approximately 147 countries and SDG 6.2.1 (percentage of population access to essential sanitation services) in about 140 countries. SDG 6, focusing on clean water and sanitation, demonstrates synergies with SDG 9, where around one-fourth of the indicator pairs, particularly 6.2.1 and 9.2.1, show a synergistic relation. For instance, 6.2.1 (percentage of the population practicing open defecation) and 9.2.1 (Carbon dioxide emissions per unit of GDP PPP).

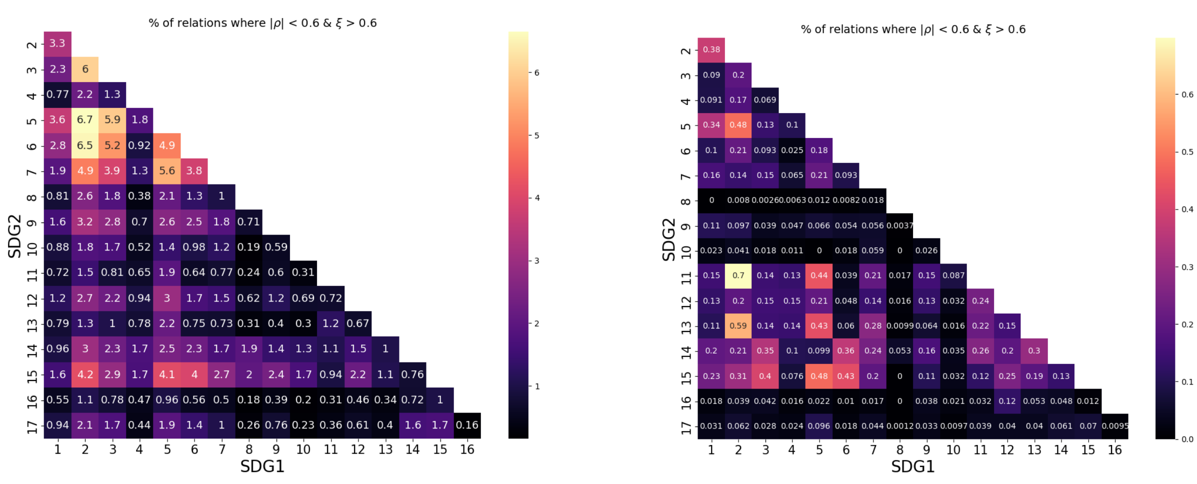
SDG 6 (clean water and sanitation) also exhibits trade-offs with SDG 9. In particular,



(a) Synergies across different SDGs at a global scale

(b) Tradeoffs across different SDGs at a global scale

Figure 4: Comparison of interactions between different SDGs globally



(a) Comparison of high $\xi > 0.6$ and low $|\rho| < 0.6$ interactions within different SDGs

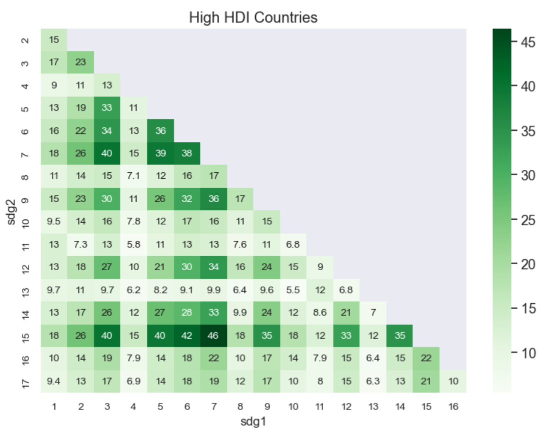
(b) Comparison of high $\xi > 0.8$ and low $|\rho| < 0.6$interactions within different SDGs indicator 6.6.1, which measures changes in the extent of water-related ecosystems over time, exhibits trade-offs with indicator 9.2.1, which assesses manufacturing value added as a percentage of GDP and per capita.

In the examination of ξ values exceeding 0.6, it becomes apparent that SDG 2 exhibits a distinctive pattern, characterized by a low Spearman correlation coefficient (ρ) and elevated ξ values (> 0.6). Focusing on SDG 3 indicator 3.2.1, which gauges infant mortality, and SDG 2 indicator related to women's anemia prevalence, an average ρ value of 0.455 is observed. Simultaneously, the average ξ value across these nations is 0.691, signifying a non-monotonic relationship. This discrepancy is particularly pronounced in around 61 countries where ξ surpasses 0.8. Notably, when transitioning to higher ξ values (> 0.8), most SDG interactions display minimal interaction, showcasing a low ρ and high ξ behavior.

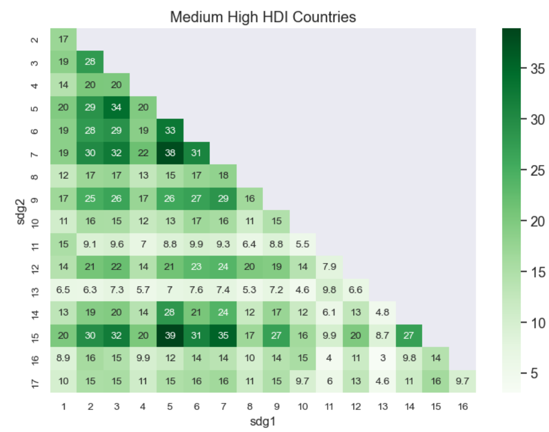
When evaluating the interaction between Sustainable Development Goals (SDGs) at different Human Development Index (HDI) levels (Fig.6 & **??**), SDG 3 (Good Health and Well-Being) consistently shows a more significant percentage of synergies across all HDI tiers. In contrast, SDG 15 (Life on Land) demonstrates notable synergies, particularly in higher HDI nations. For example, SDG 15 includes roughly 4 interactions whose synergy percentages are higher than 40% in high HDI countries as contrasted to low HDI, where just one interaction of SDG 15 has a higher rate than 40% and 0 occurrences in mid and high-medium HDI countries. In mid-high HDI countries, Sustainable Development Goal (SDG) 15, which focuses on life on land, has about 46% synergies with SDG 7, which is about affordable and clean energy. Specifically, SDG 15.1.2 (average proportion of critical terrestrial biodiversity) is highly synergistic with SDG 7.3.1 (Energy intensity level) and SDG 7.2.1 (renewable energy share in total energy production) in almost two-thirds of these countries, whereas in low HDI countries, the synergies between SDG 15 and SDG 7 drop to about 27%. Here, the noticeable synergies are mainly between SDG

7.1.1 (proportion of population with access to electricity) and SDG 7.2.1 (renewable energy share in total energy production) with SDG 15.6.1 (number of Standard Material Transfer Agreements transferring plant genetic resources to the country) and SDG 15.5.1 (Red List Index). These synergies exist in less than half of the low HDI countries.
In the case of low HDI countries, SDGs 3 and 6 (Clean Water and Sanitation) exhibit the highest number of synergies, representing 40% of indicator pairs displaying synergistic relationships. Similar to SDG 15, SDG 12 (responsible consumption and production) has a higher share of synergies in countries with high HDI while having more tradeoffs in countries with low HDI. Countries with lower Human Development Index (HDI) generally exhibit a higher share of tradeoffs across various Sustainable Development Goals (SDGs). Specifically, SDG 16 (Peace, Justice, and Strong Institutions) shows a higher share of tradeoffs in lower HDI countries, with tradeoffs observed with SDGs 1 (No Poverty), 3 (Good Health and Well-Being), 5 (Gender Equality), 6 (Clean Water and Sanitation), and 7 (Affordable and Clean Energy). Conversely, SDG 15 (Life on Land) and SDG 2 (Zero Hunger) have more pronounced tradeoffs in higher HDI countries. SDG 15 demonstrates significant tradeoffs with SDGs 2, 9 (Industry, Innovation, and Infrastructure) and 10 (Reduced Inequality), while SDG 2 also shows tradeoffs with SDGs such as SDGs 15, 9, 6, 3, and 7. In high HDI countries, there are significant trade-offs between SDG 9.4.1 (Carbon dioxide emissions per unit of GDP PPP) and SDG 15.1.2 (Average proportion of Freshwater Key Biodiversity). The scale of tradeoffs is observed in about half of the high HDI countries.

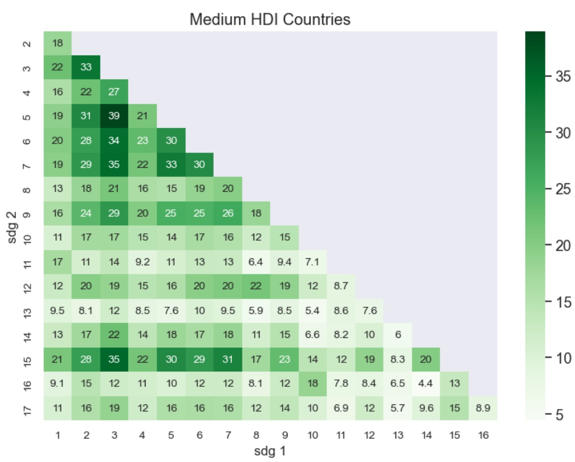
SDG 10 (Reduced Inequality) exhibits lower tradeoffs in higher HDI countries than in lower ones. For instance, the tradeoff percentage for SDG 10 and 6 in low HDI countries is 25%, whereas it is around 16-17% in high to mid-HDI countries. The key tradeoffs here are b/w SDG 6.1.2 (percentage of the population practicing open defecation) and



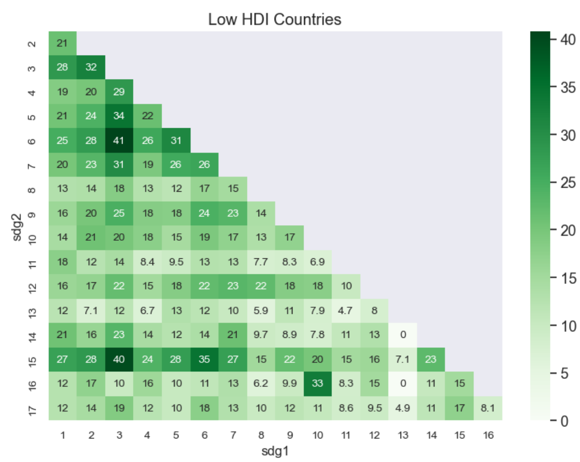
(a) Synergies across different SDGs in high HDI (≥ 0.8) countries



(b) Synergies across different SDGs in medium-high HDI ($0.8 > \text{HDI} \geq 0.7$) countries

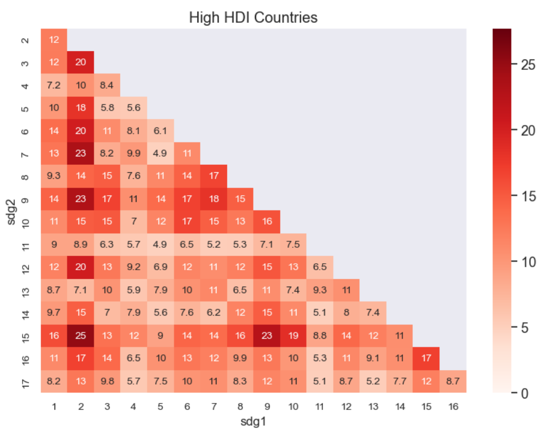


(c) Synergies across different SDGs in medium HDI ($0.7 > \text{HDI} \geq 0.5$) countries

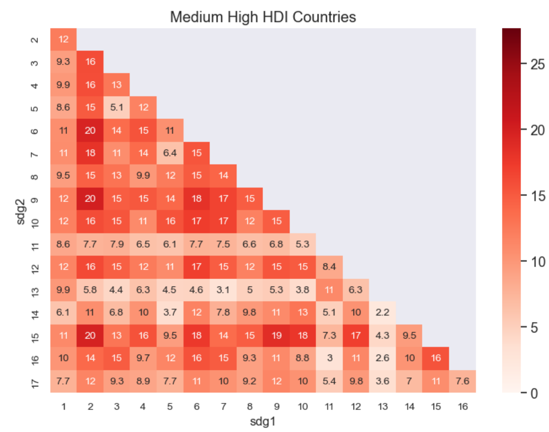


(d) Synergies across different SDGs in low HDI (< 0.5) countries

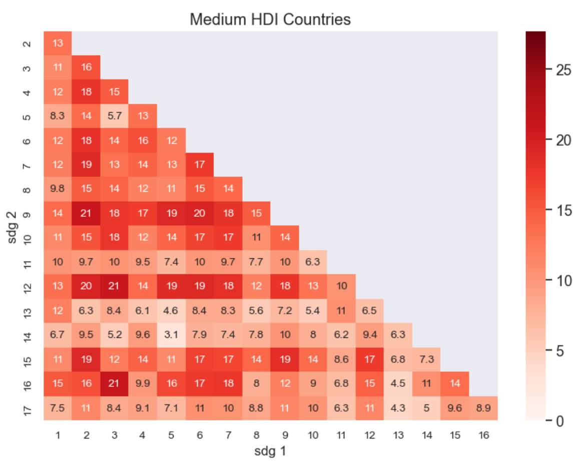
Figure 6: Comparison of Synergies across different SDGs in different HDI groups



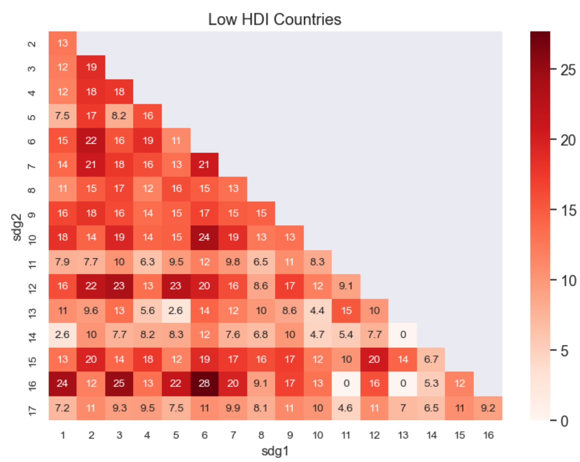
(a) Tradeoffs across different SDGs in high HDI (≥ 0.8) countries



(b) Tradeoffs across different SDGs in medium-high HDI ($0.8 > \text{HDI} \geq 0.7$) countries



(c) Tradeoffs across different SDGs in medium HDI ($0.7 > \text{HDI} \geq 0.5$) countries



(d) Tradeoffs across different SDGs in low HDI (< 0.5) countries

Figure 7: Comparison of Trade-offs across different SDGs in different HDI groups

SDG 10.b.1(Total assistance for development by recipient countries), which has tradeoffs in about 2/3 of the low HDI countries. Similarly, In low HDI countries, SDG 12 (Responsible Consumption and Production) has noticeable tradeoffs with SDGs 1, 2, 3, 5(gender equality), 7(clean and affordable energy), and 9(build resilient infrastructure).SDG 12.c.1 (Fossil fuel subsidies) has notable trade-offs with several other indicators. These include SDG 2.2.3 (Number of women with anemia), SDG 3.2.1 (Infant mortality rate), SDG 5.5.1 (Proportion of seats held by women in national parliaments). However, these tradeoffs decrease as we move from low to high HDI. Additionally, SDG 16 has the highest number of tradeoffs in low HDI countries compared to higher HDI countries, while SDG 2 exhibits significant tradeoffs across all HDI levels. Indicators with high ξ (> 0.6) and low ρ (Spearman correlation coefficient) values show a distinct pattern across HDI strata(fig4.b). SDG 2 (Zero Hunger) has many non-linear correlations in higher HDI countries, particularly with SDGs 15 (Life on Land) and 6. For example, around 8% of indicator pairs for SDG 2 and SDG 15, as well as SDG 2 and SDG 6, demonstrate nonlinear behavior. This figure steadily falls to roughly 4% in lower HDI countries. Simultaneously, in lower HDI nations, SDG 5 (Gender Equality) has a high rate of non-linear connections, with around 11% of indicator pairs demonstrating such behavior with SDGs 2, 15, 14 (Life Below Water), and 6. (clean water). However, adopting a stricter threshold for ξ (> 0.8), many of these non-linear connections disappear. It is critical to recognize that small sample sizes and missing data significantly contribute to the difficulties in understanding this non-linear pattern among SDGs. These issues highlight the necessity of resolving data limitations and evaluating how they may affect the observed connections between SDG indicators.

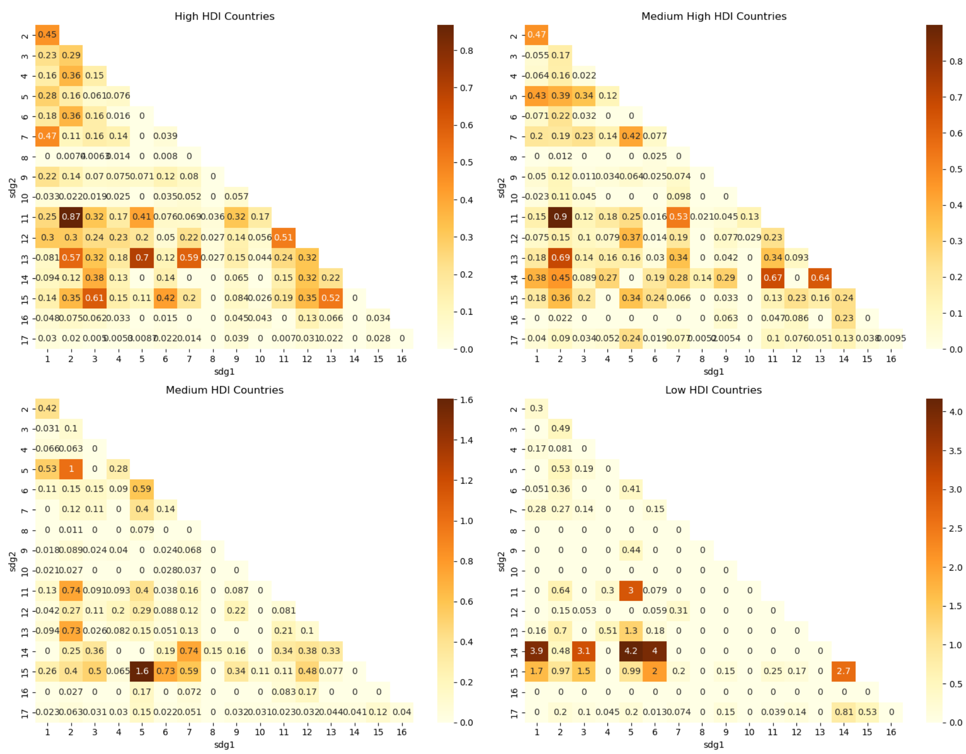


Figure 8: Comparison of high $\xi > 0.6$ and low $|\rho| < 0.6$ interactions within different SDGs within different HDI levels

4 Discussion

Implementing the SDG agenda is critical in tackling global sustainability issues such as human well-being, economic development, and environmental conservation. Given their interdependence, understanding the synergies and trade-offs of the SDGs became crucial to fulfilling the 2030 SDG agenda."To build a safe and just international system, the SDGs must work together as cogwheels rather than as isolated goals & all of them must be accomplished in tandem"(Pradhan et al. 2017). Our study replicates the findings of (Warchold, Pradhan, and Kropp 2021) and (Pradhan et al. 2017, indicating that synergies within the Sustainable Development Goals (SDGs) outweigh tradeoffs. SDGs 3 (Good Health and Well-Being), 5 (Gender Equality), 6 (Clean Water and Sanitation), 7 (Affordable and Clean Energy), and 9 (Industry, Innovation, and Infrastructure) have the highest levels of synergy, accounting for 25-33% of indicator combinations. Among these, SDG 3 (Good Health and Well-Being) has the most internal synergies. However, there are inconsistencies in the extent of synergies and trade-offs compared to the findings of (Pradhan et al. 2017). Consideration of the complete development spectrum and data gaps are the primary contributors to the observed disparities. (Warchold, Pradhan, and Kropp 2021),Furthermore, the predominance of non-classified interactions emphasizes the diversity of development paths and inequality between countries. Longitudinal analysis of a country's development can reveal these synergies (Warchold, Pradhan, and Kropp 2021).

This thesis adds significantly to the existing literature on sustainable development research in the following ways: To begin, by expanding the chronological scope of the analyzed data to 2022, this study provides a more comprehensive assessment of progress toward the Sustainable Development Goals (SDGs). Incorporating an extra 6-7 years of observations allows for a full reassessment of earlier results and aids in the identification of emergent trajectories and patterns throughout time. Despite the progress made in the last seven years, only six years remain to fulfill the SDG agenda, making trade-offs a crucial issue to consider when developing future policy. The Sustainable Development Goals (SDGs) involve major trade-offs. Particularly, SDG 2 (Zero Hunger) and SDG 9 (Industry, Innovation, and Infrastructure) have the highest trade-offs, accounting for almost 20% of all indicator pairings. This highlights the ongoing problems of eliminating global hunger and developing sustainable infrastructure. To illustrate this further, consider an SDG 9 indicator, "Manufacturing value added (constant 2015 United States dollars) as a proportion of GDP (%)," which has significant trade-offs with another SDG 9 indicator, "Carbon dioxide emissions from fuel combustion (millions of tonnes)" in roughly 109 nations. Implying that when countries focus on increasing their manufacturing value-added, they may unintentionally contribute to higher carbon dioxide emissions from fuel combustion, impeding progress towards SDG 9.(Ma et al. 2024)

Secondly, using the combination of the Chatterjee correlation coefficient((ξ)) and Spearmen correlation coefficient (ρ) as an analytical methodology enriches the study's ability to capture intricate non-linear relationships between SDG indicators. This metric, alongside the traditional Spearman rank correlation approach, offers a more nuanced comprehension of the complex interdependencies within the SDG framework. Most of the SDG interactions show monotonous behaviors and This monotone behavior heavily outweigh non-monotone behavior ((Warchold, Pradhan, and Kropp 2021)); however, We detected some non-linearity in SDG interactions within the SDG group SDG 2, SDG 6 shows some examples of nonlinear relationship (low $\rho(< 0.6)$ high $\xi(> 0.6)$) and SDG 7 in low HDI countries have a non-monotonic relationship, similarly, across SDG groupings. Indicators for SDG 2 (Zero Hunger) demonstrate a pronounced rate of non-linear correlations (as evidenced by high nonlinearity coefficient ξ and low Spearman's ρ values) with indicators for SDGs 15 (Life on Land) and 6 (Clean Water and Sanitation) in higher HDI countries. This rate of non-linear SDG 2 correlations steadily diminishes in lower HDI nations. Conversely, in lower HDI countries, indicators for SDG 5 (Gender Equality) exhibit more prolific non-linear interconnections with indicators for SDGs 2, 15, 14 (Life Below Water), and 6(clean water and sanitation). However, numerous aforementioned non-linear relationships vanish upon applying a more stringent ξ threshold (> 0.8), alluding to underlying data limitations. Small sample sizes and missing observations severely encumber efforts to characterize and comprehend non-linearity patterns amongst SDG indicators across variegated development contexts.

Understanding trade-offs among different SDGs is also crucial. For instance, SDG 6 (clean water and sanitation) entails trade-offs with SDG 9. Here, indicator 6.6.1, which evaluates changes in the extent of water-related ecosystems over time, has trade-offs with indicator 9.2.1, which measures and assesses manufacturing value added as a percentage of GDP and per capita. In the above example, a trade-off means that investments in water-related ecosystems could compete with attempts to increase manufacturing value added as a percentage of GDP and per capita. Policymakers need to strike a balance between these goals to guarantee that economic expansion safeguards environmental sustainability. The aforementioned trade-offs highlight the necessity of a sustainable shift from current development paths that prioritize economic growth above ecological sustainability in order to achieve human well-being.((Sen 1983))

Thirdly, this thesis goes beyond conventional economic indicators, such as Gross Domestic Product (GDP), by utilizing the multidimensional Human Development Index (HDI) for stratified analyses. This innovative approach allows for a deeper understanding of the variability in SDG priorities and progress trajectories across different levels of human development. By offering a more holistic perspective on the pathways toward sustainable development.A country's stage of socioeconomic history affects the importance of environmental sustainability and human well-being demands.(Lusseau and Mancini 2019) This acknowledgment underscores the importance of considering varied priorities in pursuing

Sustainable Development Goals (SDGs) across different levels of human development, as delineated by the United Nations Human Development Index (HDI), which reveals differentiated priorities in SDG interactions. The findings indicate that SDG 15 (Life on Land) has the highest proportion of synergistic interactions between indicator pairs in nations with high ($HDI > 0.7$) nations while. SDG 3 (Good Health and Well-Being) has higher synergistic potential in medium and low HDI ($HDI < 0.7$) nations. These findings suggest that countries with high levels of socioeconomic development should prioritize sustainable land use and coexistence with nature (SDG 15). At the same time, countries with low Human Development Indexes (HDI) should prioritize basic health and social services (SDG 3) to meet SDG targets. SDG 2 (Zero Hunger) and SDG 6 (Clean Water and Sanitation) have similar trade-offs and synergies in nations with all phases of human development, emphasizing their significance independent of a country's social environment. Thus, reducing world hunger and providing access to clean water and sanitation are vital to all societies. Therefore, governments should prioritize these two SDGs regardless of their country's development level.

SDGs 15 (Life on Land) and 12 (Responsible Consumption and Production) have higher synergy % in countries with higher Human Development Indexes (HDI) than in countries with lower HDI. This suggests that sustainable land use, responsible consumption, and production are critical to achieving the SDGs in wealthy countries. Promoting sustainable land use and responsible usage of these resources in higher HDI countries can greatly affect reaching the SDG agenda because it uses current, more elevated levels of synergies and solves a critical concern for these nations.

Focusing on the interlinkages between Sustainable Development Goals (SDGs) within distinctive country contexts is a potential path to achieving comprehensive and sustainable development results across multiple dimensions. In low-HDI nations, strategic emphasis should be made on leveraging synergies between activities to improve access to energy

(SDG 7.1.1) and conservation programs (SDG 15.5.1, Red List Index). By prioritizing increased electricity availability, these countries can reduce their dependency on biomass and other natural resources for energy, positively contributing to conservation efforts and biodiversity preservation. In contrast, in high HDI nations, policy interventions should prioritize harnessing synergies between growing renewable energy production (SDG 7.2.1) and maintaining key terrestrial biodiversity areas. These countries can achieve sustainable development goals while reducing negative environmental impacts by simultaneously expanding the protected status of biodiverse terrestrial ecosystems and increasing the proportion of renewable energy sources in their energy portfolios. This diversified policy approach emphasizes the need for specific actions that meet the problems and opportunities inherent in each country's unique socioeconomic and ecological context. Such strategic policymaking is critical for maximizing the synergistic potential of the SDGs and promoting sustainable development agendas globally.

In countries with high Human Development Index ($HDI > 0.8$), the strongest synergy exists between SDG 7 (Affordable and Clean Energy) and SDG 15 (Life on Land), emphasizing the importance of sustainable land use practices. Meanwhile, in medium-high HDI countries ($0.8 > HDI > 0.7$), the most significant synergistic interaction occurs between SDG 5 (Gender Equality) and SDG 15. For countries with medium HDI levels ($0.6 > HDI > 0.5$), the greatest synergy is observed between SDG 3 (Good Health and Well-being) and SDG 5. In contrast, lower HDI countries (HDI ¡ 0.5) exhibit the strongest synergy between SDG 3 and SDG 6 (Clean Water and Sanitation). These findings underscore the critical role of health initiatives in the context of low HDI levels ($HDI < 0.6$), policies on gender inclusivity in medium HDI countries ($0.5 < HDI < 0.8$), and sustainable land use practices in countries with high HDI ($HDI > 0.7$). The results emphasize the importance of tailoring SDG interventions to the specific development context of a country, leveraging the most impactful synergistic interactions to optimize progress toward achieving the SDGs.

Although correlation does not imply causation, exploiting such policy synergies through well-designed interventions can help expedite overall SDG achievement. An examination of the relationships between Sustainable Development Goals (SDGs) reveals that countries with a lower Human Development Index (HDI) encounter more trade-offs across several SDGs, notably SDGs 16 (Peace, Justice, and Strong Institutions), 15 (Life on Land), 12 (Responsible Consumption and Production), 10 (Reduced Inequality), and 2 (Zero Hunger). For instance, SDG 10 has more significant trade-offs in lower HDI countries, implying that reducing disparities is critical to implementing the SDG agenda in impoverished countries. This analysis varies from that of (Lusseau and Mancini 2019), who found that SDG 1 (No Poverty) was more structurally important in low-income nations. The key difference between the two analyses is the choice of development indicator; the current study used the Human Development Index (HDI), while Lusseau and Mancini 2019 utilized income levels.

After analyzing the relationships between several SDG spectra, we concluded that SDG 3—good health and well-being—is becoming the most important and consequential SDG. It appeared 4 times in the top 10 synergy pairs globally (fig 3) The Sustainable Development Goals (SDGs) 5 (Gender Equality), 6 (Clean Water and Sanitation), 15 (Life on Land), 9 (Industry, Innovation, and Infrastructure), and 7 (Affordable and Clean Energy) all greatly benefit from the implementation of SDG 3. SDG 3 has demonstrated strong synergistic relationships with numerous other SDGs, even when examined through various societal settings such as the Human Development Index (HDI) levels. This emphasizes the importance of putting prevention-based and inter-sectoral approaches to improving health and well-being at the top of the priority list, as Pradhan et al. 2017 recommended.

Such a strategy might have a greater influence and help achieve the SDG agenda (Buse and Hawkes 2015). As of 2024, There are only seven years left to meet the goals. More and better-quality data needs to be collected to monitor SDG progress. Data value and quality are well understood (Nilashi et al. 2023; Van Eupen et al. 2021) Without very high-quality data, sustainable development is certain to fail—a topic that has garnered little attention in prior studies. Effective impact measurement and high-quality data gathering are important for the accomplishment of SDGs(Nilashi et al. 2023). Our correlation analysis of national development indicators is insightful; it is limited by design, opening up interesting directions for further research. First and foremost, one should avoid misinterpreting correlation as causality. As such, policy recommendations based only on identified correlations require careful consideration. Second, rather than longitudinally extrapolating attainment trajectories in connection to expansive development goals, our study is limited to the current interrelationships among indicators. Third, delays in societal indicators might mask relevant relationships from real-time correlation analysis, requiring methods capable of modeling delayed effects. Furthermore, employing a symmetric version of the non-linearity coefficient(ξ) eliminates the possibility of drawing causal conclusions from asymmetric variations. More work may combine temporal and causal modeling to understand developmental relationships better. Monitoring co-movements of indicators over long periods with longitudinal data structures and asymmetric dependence metrics can improve comprehension of causal pathways and systemic time lags in the complex dynamics of sustainable development.

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appendix

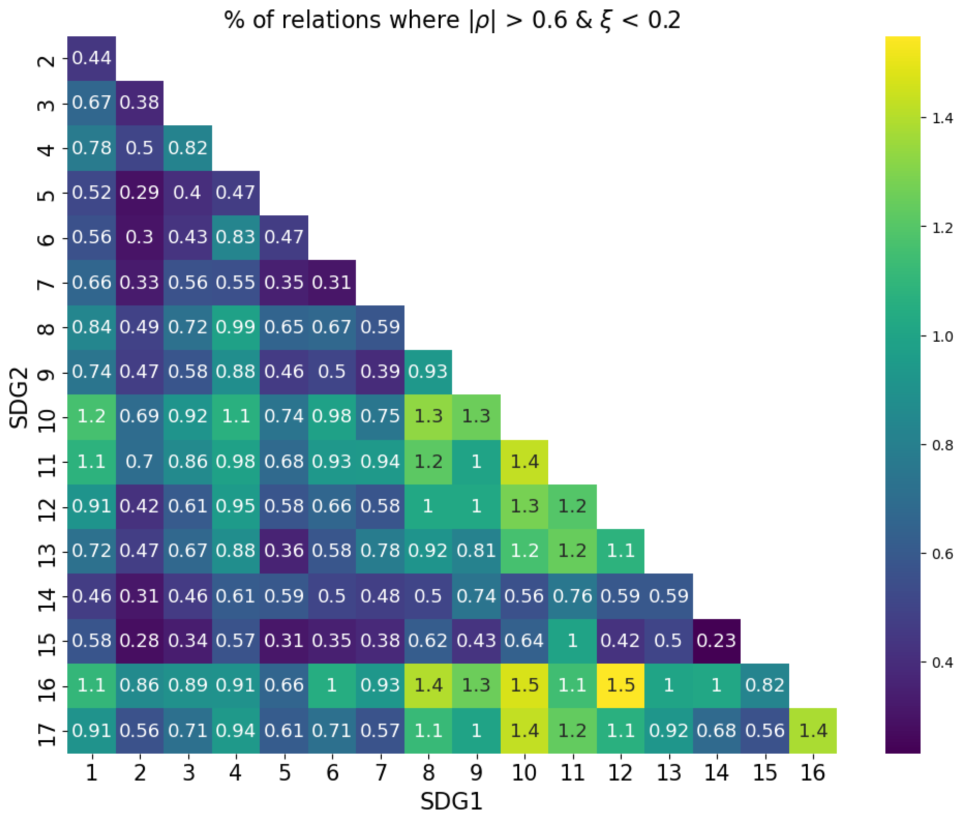

Figure 9: interactions within SDGs showcasing high $|\rho| > 0.6$ low $\xi < 0.2$