Data-Driven Approaches to Global Sustainable Development: Economic, Social, and Environmental Aspects

Merve Pakcan Tufenk

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Advisor: prof. Monica Drăgoicea

Contents

Abstract

This study examines the complex interconnections among the United Nations' Sustainable Development Goals (SDGs) through a data-driven analytical approach. By integrating quantitative modeling and structured literature analysis, this research highlights key synergies and trade-offs across economic, social, and environmental dimensions. A systematic literature review, following the PRISMA methodology, ensures methodological rigor in identifying high-impact studies. The findings contribute to a deeper understanding of how progress in specific SDGs influences broader sustainability outcomes, offering insights that enhance strategic planning and interdisciplinary collaboration. This study provides a structured framework for assessing SDG interdependencies, supporting more integrated and evidence-based approaches to sustainable development.

Keywords: Sustainable Development Goals, Data Analytics, SDG Interdependencies, PRISMA Methodology, Quantitative Modeling, Sustainability Trade-offs and Synergies, Computational Sustainability

Chapter 1

Introduction

The commitment to achieving sustainable development involves balancing its economic, social, and environmental dimensions in an integrated manner UN (2015).

At the UN headquarters in New York, the Open Working Group, established by the UN General Assembly, proposed 17 Sustainable Development Goals (SDGs) and 169 targets, along with a preliminary set of 330 indicators in March 2015. Some goals build on the Millennium Development Goals, while others introduce new concepts Hák et al. (2016).

The primary aim of the Sustainable Development Goals (SDGs) is to achieve a better and more sustainable future by 2030. These goals focus on eradicating poverty and hunger, reducing inequalities, fostering inclusive and peaceful societies, promoting human rights and gender equality, and ensuring the protection of the planet and its natural resources for current and future generations UN (2015).The SDGs aim to drive action on critical global issues, relying on efforts from governments, the private sector, civil society, and individuals. Progress is monitored through voluntary reviews that assess different goals and their interactions, with a particular focus on SDG 17 through annual reporting UN (2016).Moving towards a more comprehensive and inclusive framework for sustainable development represents a significant step forward. As outlined in the 2030 Agenda for Sustainable Development, the SDGs are designed to be integrated and indivisible, ensuring a balanced approach that considers economic, social, and environmental dimensions UN (2015).

All SDGs interact with one another – by design they are an integrated set of global priorities and objectives that are fundamentally interdependent Griggs et al. (2017), p.8. Understanding the range of positive and negative interactions among SDGs is key to unlocking their full potential at any scale, as well as to ensuring that progress made in some areas is not made at the expense of progress in others Griggs et al. (2017). This interconnection highlights the necessity of treating the SDGs as a cohesive system rather than isolated goals. Addressing them individually risks overlooking critical synergies and trade-offs that exist across their targets.

Although the SDGs were designed as an integrated system, their implementation often lacks a structured approach to managing goal interdependencies Scharlemann et al. (2020). Positive and negative interactions between targets are frequently overlooked, leading to uncoordinated strategies that may unintentionally weaken progress in related areas Nilsson et al. (2018). Addressing SDGs in isolation risks missing critical synergies and trade-offs, ultimately reducing the effectiveness of sustainability efforts Pradhan et al. (2017). Furthermore, existing policy and evaluation frameworks frequently fail to capture these systemic interactions, resulting in fragmented decision-making Bennich et al. (2020).

The interconnected and complex nature of the SDGs requires a comprehensive approach to measuring progress that considers their overlapping and interdependent dynamics. To effectively evaluate progress in these goals, it is vital to develop specialized Key Performance Indicators (KPIs) that can reflect the multifaceted relationships and interactions inherent in the SDG framework. As Pradhan et al. (2017) highlight, leveraging synergies and addressing trade-offs are crucial to achieving meaningful progress. This paper seeks to examine these interconnections and dependencies, proposing a robust framework of KPIs that ensures a holistic and accurate assessment of sustainability outcomes, ultimately facilitating more informed and integrated decision-making.

The structure of this paper is as follows: Section 2 outlines the research methodology, detailing the PRISMA approach for systematically collecting and selecting relevant articles. Section 3 evaluates existing literature on data-driven approaches to sustainability and SDGs, exploring possible collections, assessing whether information has been used to demonstrate real connections, and analyzing broader implications to understand the possible relationships between them.Section 4 discusses the findings, analyzing their implications for sustainability and exploring interdependencies between data-driven strategies. Finally, Section 5 summarizes the conclusions, reflecting on the study's contributions and suggesting directions for future research.

Chapter 2

Methodology

This study employs a structured approach to systematically collect and analyze relevant academic literature on Sustainable Development Goals (SDGs). The methodology consists of two main phases: article collection and text preparation, ensuring that the selected literature aligns with high-impact scientific standards and methodological rigor.

2.1 Article Collection

2.1.1 Search Strategy

To ensure a comprehensive and high-quality literature review, a structured search strategy was implemented using Google Scholar for initial broad coverage and Web of Science for a refined selection of peer-reviewed studies.

The search queries included terms such as:

- "A systematic study of sustainable development goal (SDG) interactions"
- "SDG trade-offs and synergies"
- "Data-driven approaches to SDG measurement"

2.1.2 Filtering and Data Source Validation

- Language Filter: To maintain consistency in interpretation, only English-language publications were included.
- Dataset Use: One dataset from Web of Science was used for validation.
- Time Frame: The research focused on studies published from 2016 onwards.
- Source Types: The majority of the selected sources are peer-reviewed journal articles, ensuring a strong academic foundation. Books, policy reports, and conference papers were considered selectively for their methodological or practical contributions.

Additionally, priority was given to highly cited studies, authors with a strong research impact (H-index), and articles published in high-ranking journals (Q1 and Q2) indexed in Web of Science to ensure academic credibility.

2.2 Text Preparation

The literature review process in this study follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology, a widely recognized framework for conducting systematic literature reviews, ensuring transparency, completeness, and comparability Moher et al. (2009).

The article selection process was conducted in four key stages:

- Identification: A comprehensive literature search was conducted using Web of Science, applying predefined keywords and inclusion criteria.
- Screening: Duplicate records were removed, followed by a title and abstract review to eliminate studies unrelated to SDG interactions and analytics.
- Eligibility: The full texts of the remaining studies were assessed for methodological quality, data availability, and relevance to the research objectives.
- Inclusion: The final set of highly relevant studies was selected for analysis. The selection process prioritized empirical data, novel methodologies, and critical insights into SDG interdependencies.

A PRISMA flow diagram was created to visually represent the selection process, ensuring clarity and reproducibility (Figure 2.1). By adopting PRISMA guidelines, this study enhances the credibility and methodological transparency of its findings, providing a structured foundation for analyzing SDG trade-offs and synergies.

The study selection followed a structured four-stage approach (illustrated in the PRISMA diagram below):

- Screening: A total of 247 records were retrieved from Web of Science, with 1 duplicate removed. The remaining 246 studies were screened based on title and abstract, leading to the exclusion of 130 studies that did not align with the research objectives.
- Full-Text Review: Out of 116 studies retrieved, 7 were inaccessible due to institutional restrictions or paywalls. The remaining 109 full-text articles underwent a detailed evaluation for methodological rigor, data quality, and relevance.
- Exclusions and Validation: A total of 89 studies were excluded, including 78 unrelated to research topics, 6 with methodological weaknesses (insufficient data or unclear methods), and 5 non-English studies. The eligibility assessment ensured that only high-quality and impactful studies progressed further.
- Final Inclusion and Quality Assurance: A total of 20 studies met all inclusion criteria and were selected for analysis. A final validation step was conducted to ensure consistency and accuracy in paper selection, reducing the risk of bias. The selected studies prioritized empirical data, novel methodologies, and key insights into SDG interdependencies.

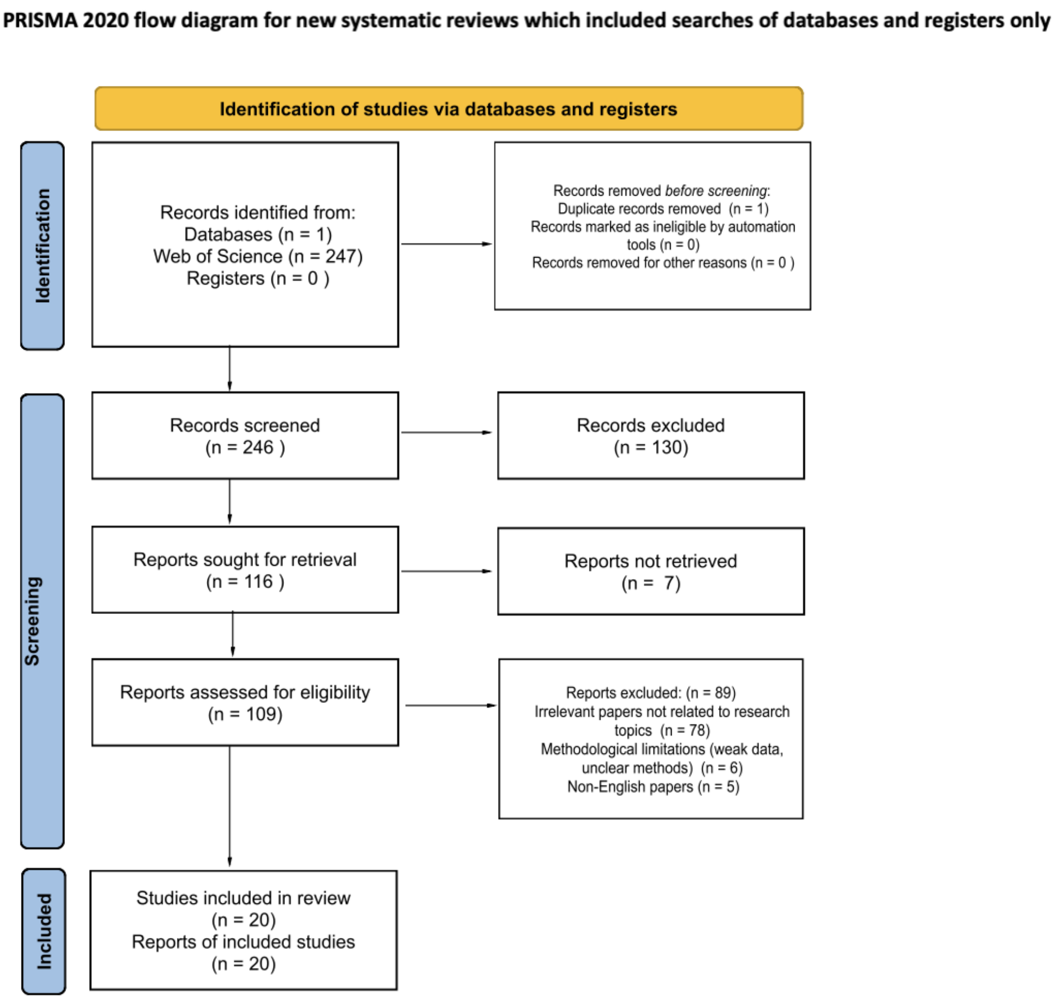

Figure 2.1: Systematic literature review and reporting - PRISMA Flow Diagram

Chapter 3

Results: State-of-the-art

To evaluate the state-of-the-art for the topic of this report, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method has been used Moher et al. (2009), Sarkis-Onofre et al. (2021). In this section, the existing literature will be reviewed to investigate and understand the possible relationships among the Sustainable Development Goals (SDGs). By examining current studies, this part aims to identify the synergies and potential trade-offs within the SDG framework, providing a comprehensive understanding of how these goals interact and influence one another.

3.1 Synergies Across SDGs

Many SDGs create positive reinforcement loops, where progress in one area accelerates improvements in others. The following key synergies have been highlighted in the literature:

- Social and Economic Synergies: SDG 1 (No Poverty) and SDG 2 (Zero Hunger) significantly contribute to SDG 3 (Good Health and Well-being) by improving nutrition and living conditions Barbier and Burgess (2019) Pradhan et al. (2017). Enhanced health outcomes, in turn, increase productivity, thereby strengthening SDG 8 (Decent Work and Economic Growth).
- Expanding clean water access (SDG 6) and renewable energy solutions (SDG 7) fosters economic growth, improves public health, and enhances overall quality of life Pradhan et al. (2017). These initiatives create a positive feedback loop, where improved water and energy availability boost agricultural productivity, industrial efficiency, and sustainable urban development. Furthermore, aligning these advancements with responsible consumption and production (SDG 12) enhances their long-term sustainability, ensuring that economic benefits are maintained while preserving natural resources Fuso Nerini et al. (2018).
- Urbanization and Innovation: Sustainable urban development (SDG 11) serves as a catalyst for technological advancements and infrastructure improvements (SDG 9), which in turn foster long-term economic stability and resilience UN (2019). Well-planned urbanization enhances resource efficiency, reduces inequalities, and stimulates economic opportunities. By integrating smart city planning and sustainable infrastructure, urbanization can drive green innovations, optimize energy consumption,

and create more inclusive economic growth, further strengthening synergies among SDGs. Aligning these developments with responsible consumption and production (SDG 12) is essential to ensuring long-term sustainability.

3.2 Trade-Offs and Challenges in SDG Implementation

Despite these synergies, some SDGs inherently conflict with others, creating policy dilemmas that necessitate strategic trade-offs. The following key trade-offs have been identified:

- Economic Growth vs. Environmental Protection: While industrialization (SDG 9) and economic growth (SDG 8) contribute to poverty alleviation (SDG 1), they also increase energy consumption and environmental degradation, potentially conflicting with SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action) Fuso Nerini et al. (2018). A key challenge is balancing economic growth with sustainable production models.

- Food Security vs. Ecosystem Sustainability: Expanding agricultural production to achieve food security (SDG 2) often results in higher water consumption (SDG 6) and deforestation (SDG 15). Sustainable agricultural practices and biodiversity conservation strategies are crucial to minimizing these environmental trade-offs.

- Climate Action vs. Employment Stability: The transition to a low-carbon economy (SDG 13) may disrupt traditional industries, particularly those reliant on fossil fuels, leading to short-term job losses and economic instability Lusseau and Mancini (2019). Addressing these employment challenges requires equitable transition policies that support reskilling and job creation in emerging green sectors.

3.3 The Role of Integrated Policymaking

The interconnected nature of the SDGs means that progress in one area has cascading effects across multiple goals. Recognizing these interactions allows policymakers to:

- Maximize synergies by aligning economic, social, and environmental objectives.

- Mitigate trade-offs through cross-sector strategies such as sustainable resource management, circular economy models, and just transition policies.

- Leverage global partnerships (SDG 17) to enhance knowledge-sharing, financial support, and policy alignment, ensuring balanced progress across all SDGs Moyer and Bohl (2019).

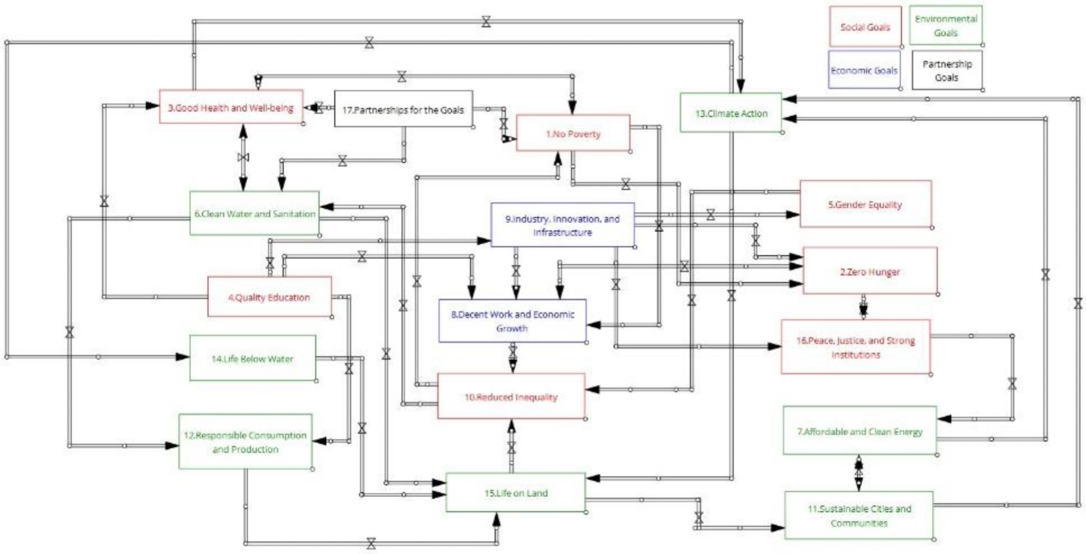

Figure 3.1: Stock-Flow Diagram Illustrating Interdependencies Among SDGs. Source: Luchian et al. (2025)

The diagram above illustrates the complex interdependencies between social, economic, and environmental SDGs Luchian et al. (2025). It highlights the reinforcing effects among key goals such as poverty reduction (SDG 1), economic growth (SDG 8), and industrial innovation (SDG 9) while also visualizing the potential conflicts, such as those between climate action (SDG 13) and industrial expansion (SDG 9). Understanding these linkages is essential for designing integrated policies that balance sustainability priorities.

Furthermore, SDG 17 (Partnerships for the Goals) acts as a fundamental connector, linking economic (SDG 8, 9), social (SDG 1, 3, 4), and environmental (SDG 6, 7, 12, 13) dimensions. By fostering global cooperation, knowledge-sharing, and resource mobilization, SDG 17 plays a key role in ensuring a holistic and coordinated approach to achieving sustainable development.

Chapter 4

Discussion

4.1 The Role of Data in SDG Implementation and Monitoring

The effective implementation and monitoring of Sustainable Development Goals (SDGs) depend on decision-makers having access to adequate data and robust analytical tools. By leveraging data analytics techniques, valuable insights and patterns can be extracted from comprehensive data sources, enabling informed decision-making to support sustainable growth. However, poor-quality, outdated, or incomplete data significantly hinder the ability to accurately assess SDG progress, particularly when making comparisons over time or across nations. To achieve meaningful progress, the availability of reliable, consistent, and comparable data is essential. Moreover, the lack of regularly updated and publicly accessible indicators further exacerbates the challenges of tracking SDGs effectively Nilashi et al. (2023).

Achieving sustainable development goals relies heavily on the availability of high-quality data, as poor data quality significantly undermines decision-making and analytical accuracy. The lack of high-quality data is a common pitfall, further complicating efforts to generate reliable insights Meng (2021).

Achieving SDGs relies heavily on high-quality data, as poor data quality significantly undermines decision-making and analytical accuracy (Meng, 2021). The integration of data analytics plays a pivotal role in addressing these challenges, ensuring data-driven, evidence-based policymaking. However, data accessibility and quality remain critical barriers that affect the assessment and deployment of SDG-related initiatives (Dang et al., 2014). Addressing external pressures, such as privacy and security concerns, and fostering robust governance frameworks are also crucial to ensuring the responsible use of big data for SDG progress Salleh and Janczewski (2019).

Therefore, adopting a comprehensive and integrated data-driven approach is essential to holistically measure and understand sustainability. This requires synthesizing diverse data sources and aligning them with the interconnected nature of SDGs, ultimately providing a robust framework for sustainability assessment and informed decision-making Teh and Rana (2023).

4.2 Challenges in SDG Data Collection and Availability

Understanding how SDG-related data is collected is essential for evaluating global progress. However, data collection presents significant challenges, as it requires contributions from various national and international sources and the use of innovative statistical methodologies. The UN SDG database integrates data from nearly 200 sources, yet a considerable portion remains missing, particularly for low-income countries. Only about 19 percent of the required data is available for comprehensively tracking global SDG progress Dang and Serajuddin (2020).

To address these gaps, international organizations play a crucial role in data curation, standardization, and imputation-based statistical techniques, which can serve as cost-effective solutions when actual survey data is unavailable. Moreover, evolving data needs call for the inclusion of alternative indicators, such as subjective well-being measures, which complement traditional economic statistics. Strengthening national statistical capacity and fostering collaboration between stakeholders remain essential steps in improving the availability and reliability of SDG-related data.

4.3 Empirical Evidence on SDG Interconnections

As seen in the Figure 4.1, a comprehensive review of methods used to analyze SDG interdependencies is provided with categorizing them into argumentative, literature-based, linguistic, simulation, statistical, and other quantitative approaches Horvath et al. (2022). The findings highlight that different methods serve distinct purposes—argumentative models like causal loop diagrams conceptualize systemic connections, while simulation techniques such as agent-based modeling enable dynamic scenario testing. Statistical methods, including correlation analysis and regression models, offer empirical insights but often struggle with causality Horvath et al. (2022).

As research shifts towards data-driven methodologies, integrating both qualitative and quantitative approaches has become essential. While previous studies have relied heavily on literature synthesis and conceptual modeling, recent advancements emphasize computational and empirical techniques Horvath et al. (2022). While other studies have used different techniques, this project will utilize a data-driven approach and system dynamics.

Categories and assigned methods to analyse SDG entity interactions.

Category	Method	Refs.
Argumentative	Bayesian belief network (BBN)	(Hall et al., 2018)
	Causal loop diagram (CLD)	(Zhang et al., 2016)
	Cross-impact matrix (CI matrix)	(Allen et al., 2019a; Dawes, 2020; Kumar et al., 2018; Weitz et al., 2018; Zaini and Akhtar, 2019; Zelinka and Amadei, 2017)
	Structured elicitation of expert information (Expert)	(Allen et al., 2019a; Bhaduri et al., 2016; Hall et al., 2018; Hazarika and Jandl, 2019; Jaramillo et al., 2019; Waage et al., 2015; Wieser et al., 2019)
	Nilsson scale (N Scale)	(Allen et al., 2019a; Fader et al., 2018; Fuso Nerini et al., 2019; Hall et al., 2017; Hazarika and Jandl, 2019; Jaramillo et al., 2019; McCollum et al., 2018; Nilsson et al., 2016; Singh et al., 2018; Weitz et al., 2018; Zelinka and Amadei, 2017)
Literature	Non-systematic literature review (Non-syst)	(Alcamo, 2019; Bringezu, 2018; Fisher et al., 2017; Haines et al., 2017; Hazarika and Jandl, 2019; Manandhar et al., 2018; Morton et al., 2017; Pandey and Kumar, 2018; Recuero Virto, 2018; Swamy et al., 2018; Wydra et al., 2019)
	Semi-systematic literature review (Semi-syst)	(Bangert et al., 2017; De Paiva Serôa Da Motta, 2019; Engström et al., 2018; Fuso Nerini et al., 2019, 2018; Hanjra et al., 2016; Hepp et al., 2019; Schroeder et al., 2019)
	Systematic literature review (Syst)	(Alcamo, 2019; Blicharska et al., 2019; Davide et al., 2019)
	Review of case studies (Case studies)	(Alcamo, 2019; Velis et al., 2017)
Linguistic	Keyword analysis (KWA)	(De Paiva Serôa Da Motta, 2019; Le Blanc, 2015; Nugent et al., 2018)
Simulation	Agent based modelling (ABM)	(Wang et al., 2019)
	Computable general equilibrium models (CGE)	(Banerjee et al., 2019; Campagnolo and Davide, 2019; Doelman et al., 2019; Lucas et al., 2019; Matsumoto et al., 2019; Schütze et al., 2017)
	Energy system models (ESM)	(Engström et al., 2019; Vandyck et al., 2018)
	Integrated assessment models (IAM)	(Doelman et al., 2019; Fujimori et al., 2019; Gao and Bryan, 2017; Heck et al., 2018; Hutton et al., 2018; Lucas et al., 2019; Matsumoto et al., 2019; Obersteiner et al., 2016; Rao et al., 2016; von Stechow et al., 2016; Zhang et al., 2019)
	System dynamics modelling (SD)	(Allen et al., 2019b; Collste et al., 2017; Dawes, 2020; Pedercini et al., 2019, 2018; Spaiser et al., 2017)
Other quantitative	Accounting framework (Account)	(Engström et al., 2018)
	Network analysis (NWA)	(Allen et al., 2019a; Dörgő et al., 2018; Feng et al., 2019; Jaramillo et al., 2019; Jiménez-Aceituno et al., 2020; Kunčič, 2019; Le Blanc, 2015; Lim et al., 2018; Lusseau and Mancini, 2019; Mainali et al., 2018; McGowan et al., 2019; Nugent et al., 2018; Sebestyén et al., 2019a, 2019b; Weitz et al., 2018; Zelinka and Amadei, 2017)
	Environmentally-extended multi-regional input-output models (IO)	(Hubacek et al., 2017; Scherer et al., 2018)
Statistical	Advanced sustainability analysis (ASA)	(Mainali et al., 2018)
	Autoregressive distributive lag bounds test (ARDL)	(Ngarava et al., 2019)
	Correlation analysis (Corr)	(Brecha, 2019; Donaires et al., 2019; Kroll et al., 2019; Mainali et al., 2018; Ngarava et al., 2019; Pradhan et al., 2017; Sebestyén et al., 2019a, 2019b)
	Cox proportional hazards models (CPH)	(Akinyemi et al., 2018)
	Descriptive statistics (Descr)	(Howden-Chapman et al., 2020)
	Generalised method of moments (GMM)	(Matthew et al., 2019; Shahbaz et al., 2019)
	Joint correspondence analysis (JCA)	(Ulman et al., 2018)
	Linear mixed effect models (LMM)	(Lusseau and Mancini, 2019)
	Pairwise granger causality test (PGC)	(Ngarava et al., 2019)
	Principal component analysis and Factor analysis (PCA&FA)	(Donaires et al., 2019; Feng et al., 2019; Sen and Ongsakul, 2018; Spaiser et al., 2017)
	Quantile regression, bootstrapped (Q Reg)	(Sinha et al., 2020)
	Regression analysis (Reg)	(Buonocore et al., 2019; Cluver et al., 2016; Hall et al., 2017; Malerba, 2019; Obersteiner et al., 2016; Ramos et al., 2018; Ulman et al., 2018)

Figure 4.1: Source: Horvath et al. (2022)

Chapter 5

Conclusion

A data-driven approach will be essential for effectively assessing sustainability. This requires integrating diverse data sources and aligning them with the interconnected nature of Sustainable Development Goals (SDGs), ultimately providing a robust framework for sustainability assessment and evidence-based decision-making Dang and Serajuddin (2020).

Despite challenges in data accessibility, quality, and standardization, studies have demonstrated real connections between SDGs, reinforcing the need for data-driven policymaking. Moving forward, the integration of data analytics and real-time monitoring will be key to improving SDG tracking and ensuring sustainable development pathways.

5.1 Future Research Directions

5.1.1 System Dynamics Method for SDG Analysis

To better understand SDG interdependencies, system dynamics models and stock-flow diagrams will be explored. These tools can help visualize feedback loops, time delays, and trade-offs in sustainability policies. Future research should apply these techniques to analyze interactions among goals like poverty reduction (SDG1), health (SDG3), and economic growth (SDG8), as well as potential conflicts, e.g., between clean energy (SDG7) and responsible consumption (SDG12). Incorporating system dynamics modeling will provide a more comprehensive view of sustainability challenges and support data-driven policy decisions.

Utilizing Large-Scale Databases for SDG Tracking

Enhancing real-time SDG monitoring will require integrating multiple databases from various perspectives. Key sources for future research include:

- Industrial Ecology Data Commons (IEDC): Provides diverse industrial ecology datasets, including resource use, material flows, and input-output data, supporting sustainability assessments (https://www.database.industrialecology.uni-freiburg.de).
- GDELT (Global Database of Events, Language, and Tone): Tracks social, economic, and political events affecting SDG progress (https://www.gdeltproject.org/).

- The Proxy Indicator Approach will be explored to assess SDG progress when direct measurements are unavailable. Using indirect indicators as proxies can enhance sustainability assessments by providing alternative insights into complex systems.

Combining these databases with predictive analytics will enable more dynamic and precise sustainability assessments, supporting data-driven evaluations.

5.2 Final Remarks

Future research will prioritize the integration of data-driven methodologies with dynamic modeling to improve sustainability tracking and comprehensive assessments. While synergies between SDGs create significant opportunities for integrated progress, trade-offs remain a critical challenge. Addressing these contradictions requires multi-sectoral, data-driven strategies that incorporate diverse socio-economic contexts. Future research should focus on refining analytical frameworks that balance economic growth, environmental sustainability, and social equity, ensuring that sustainability efforts are both effective and inclusive UN (2019).

By leveraging advanced data analytics, system dynamics approaches, proxy indicator, and stock-flow diagram, SDG progress can be more effectively monitored, leading to deeper insights and enhanced sustainability evaluations.

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