Exploring the Interlinkages Between Education and Sustainable Development Goals: An Advanced Text Mining and Network Analysis Approach

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Abstract

This research addresses the critical gap in understanding how education (SDG 4) interlinks with other SDGs. While education is widely recognized as a key driver of sustainable development, current research lacks a comprehensive analysis of its broader connections across the SDG framework. To tackle this issue, the research utilizes advanced methodologies, such as text mining and network analysis, to explore the interlinkages between SDG 4 and other SDGs. By analyzing 78 UN flagship reports containing approximately 1.6 GB of data and 12.8 million words, the research extracted and analyzed around 18,000 education-related statements. Using social network analysis, bipartite network visualization, and topic modeling, the research uncovered the hidden patterns and connections. Key results revealed strong linkages between education and goals related to economic growth, gender equality, and innovation. Additionally, an SDG-SDG network analysis highlighted the central role of SDG 8 (Decent Work and Economic Growth). Topic modeling further identified thematic areas for each SDG, ranging from poverty reduction and gender empowerment to climate action and environmental conservation. These findings provide valuable insights into the diverse ways education drives sustainable development, offering a data-driven foundation for policymakers and stakeholders. The research highlights the importance of implementing comprehensive policy strategies that fully harness the transformative potential of education to advance sustainable development.

Keywords: SDGs, Education, Text Mining, Topic Modelling, Network Analysis.

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1. Introduction

The Sustainable Development Goals (SDGs), adopted by UN member states in 2015, represent a significant step in tackling global socio-economic and environmental challenges from 2015 to 2030. They build on the Millennium Development Goals (MDGs) and expand to include a broader range of issues such as poverty eradication, climate action, and economic growth. This comprehensive approach reflects the interlinkages of social, economic, and environmental dimensions. However, the MDGs, the SDGs are designed to be universal, applying to both developed and developing countries, thereby emphasizing the shared responsibility of all nations in addressing these common challenges and advancing sustainable development (Mantlana et al.,2016)

A holistic approach to sustainable development is essential for tackling systemic challenges and achieving lasting progress. Integrating the interlinkages among the SDGs into policies can lead to more effective responses by aligning national priorities with global goals. Given the complexity of sustainable development, it is crucial to incorporate the SDGs into policy design and implementation. This approach maximizes synergies, minimizes trade-offs, and fosters progress across various dimensions. For example, poverty reduction efforts must consider education, healthcare, economic growth, environmental sustainability, and social equity.

Education is widely recognized for its enabling role in many sustainable development areas within the SDGs, including economic growth, poverty reduction, gender equality, and health (Vladimirova and Le Blanc, 2016). SDG 4, dedicated to education as a standalone goal within SDGs, highlights its enduring importance in the global development agenda.

The interlinkages between education and other SDGs can be extracted and analyzed from global flagship reports, as these reports are well-documented by prestigious institutions such as the World Bank and the United Nations Development Programme (UNDP). These comprehensive reports underscore the complex and multifaceted

linkages between education and various dimensions of sustainable development (Le Blanc et al., 2017; Vladimirova and Le Blanc, 2016).

Examining these reports provides evidence-based data that underscores the important role of education in achieving the SDGs. Education, when integrated with other SDGs, can enhance the effectiveness of interventions aimed at achieving the SDGs (Ayo and Daet, 2024). For example, integrating education with SDGs such as Quality Education, Gender Equality, and Climate Change enhances the effectiveness of achieving the SDGs by 2030. Similarly, incorporating environmental education into school curricula can foster a generation of environmentally conscious citizens who are better equipped to address climate change and environmental degradation.

The flagship reports from the World Bank and UNDP highlight the critical role of education in achieving sustainable development. They advocate for integrated approaches that leverage the synergies between education and other SDG areas, ensuring a holistic and effective strategy to overcome the multifaceted challenges of sustainable development (Vladimirova and Le Blanc, 2016).

Exploring the synergies between education and other SDGs are essential for maximizing the impact of educational interventions and advancing progress towards SDGs (Agusdinata, 2022). By integrating education into broader development strategies and fostering interdisciplinary collaboration, policymakers can unlock the transformative potential of education as a holistic and inclusive development.

The importance of this research lies in its contribution to sustainable development research through the application of advanced text mining and network analysis techniques. By investigating the interlinkages between education (SDG 4) and other SDGs, the research provides new insights into education's role in achieving broader sustainability goals. Utilizing a large dataset of 78 UN flagship reports -amounting to 1.6 GB of data and 12.8 million words- alongside methodologies such as bipartite network analysis and topic modeling, the research offers a detailed, data-driven exploration of SDG interlinkages. In the current global context, where education is seen

as a foundation for progress in poverty reduction, economic growth, gender equality, and environmental sustainability, this research reveals how education influences these areas (Aada, 2024).

The research problem stems from the limited understanding of how education (SDG 4) connects with other SDGs, despite its acknowledged significance. Existing studies tend to be fragmented, focusing on individual goals rather than offering a holistic approach. To address this gap, this research applies advanced techniques to uncover hidden patterns and relationships between SDG 4 and the broader SDG framework. The research aims to offer a comprehensive view of education's influence on sustainable development. Since education's connections with other goals are often implicit, computational methods are essential for revealing indirect relationships, such as the link between SDG 4 and SDG 1 (No Poverty).

The primary objective is to generate valuable insights that inform more effective, data-driven strategies, enabling policymakers and stakeholders to develop holistic approaches that enhance synergies and reduce trade-offs across multiple SDGs, leveraging education's potential to drive progress on a broader scale.

This research is structured as follows: Section 2 provides the Literature Review, Section 3 outlines the Methodology, Section 4 presents the results of the methodology, and Section 5 concludes with the Conclusion and Recommendations.

2. Literature Review

Vladimirova and Le Blanc (2016) analyzed 37 UN flagship reports to examine the interlinkages between education (SDG 4) and other SDGs. The research found that education is linked with almost all SDGs, except for SDG 14 (oceans), highlighting the critical role education plays across various dimensions of sustainable development. They observed that while certain goal areas, such as social inclusion and economic development, received more attention, many links, particularly with environmental goals, were not thoroughly explored. The research emphasizes the need for a comprehensive assessment of these links to ensure the integration of education in SD

efforts. Furthermore, the research highlights the importance of understanding these interlinkages to inform and stimulate policy-making processes, thereby promoting a more integrated approach to achieving the SDGs.

Le Blanc et al. (2017) conducted an exploratory study to map the interlinkages among the targets of SDG 14, which focuses on oceans, and other SDGs. By reviewing numerous UN reports and scientific publications, they identified that many targets within SDG 14 are synergistic, meaning progress in one target can support progress in others. Their analysis revealed significant linkages between SDG 14 and other SDGs, particularly with those related to environmental sustainability, economic development, and social inclusion. For instance, they found connections between ocean health and SDGs 1 (No Poverty), 2 (Zero Hunger), 8 (Decent Work and Economic Growth), and 13 (Climate Action). The study provided a framework for understanding these complex interrelationships, which is crucial for policy discussions aimed at advancing SDG 14. It highlighted that achieving sustainable ocean management requires integrated strategies that consider the interdependencies with other SDGs.

Alcamo (2019) reviewed the explicit and inferred interlinkages between water quality and various SDG targets, demonstrating how improvements in water quality can contribute to broader sustainable development objectives. The paper identifies key interlinkages, particularly within the context of SDG 6 (Clean Water and Sanitation) and illustrates these through multiple case studies. The author emphasizes the need for new indicators to effectively monitor these interlinkages and suggests that collaborative efforts between the water quality sector and other areas can lead to mutual benefits in achieving SDG targets.

Mantlana and Maoela (2020) conducted a comprehensive review of scientific publications and relevant reports to evaluate the interlinkages between SDG 9, which focuses on industrial innovation and infrastructure, and other SDGs related to social inclusion (SDGs 2 and 11), environmental sustainability (SDGs 6, 13, and 15), and economic development (SDG 7). The results indicated that co-benefits were the most

prevalent interlinkages, especially between SDG 9 and the other SDGs considered. SDG 2 exhibited the highest number of neutral interlinkages with SDG 9, while trade-offs were primarily observed with SDGs 6, 13, and 15. The study highlights the importance of understanding these interlinkages to inform and stimulate policy dialogues, emphasizing their significance in the implementation, monitoring, and reporting of SDG 9 targets.

Cling and Delecourt (2022) conducted a comprehensive review of scientific publications and relevant reports to evaluate the interlinkages between the SDGs, focusing on the correlations between various SDG indicators to identify synergies and trade-offs. Their key findings reveal that human development and economic development are strongly interconnected, with human development significantly contributing to the variance in global SDG indicators. Intermediate and poor countries show similar patterns in SDGs related to human development, with SDGs 1-4 (poverty, hunger, health, and education) being critical contributors. The study concludes that differences in SDG indicator performances among countries are mainly due to economic development levels, reinforcing the relevance of holistic development policies that consider the interconnected nature of sustainable development goals.

Coenen et al. (2022) explores the interactions between climate actions and SDGs through a network analysis approach. The study focuses on transnational climate initiatives (TCIs) registered in the Non-State Actor Zone for Climate Action (NAZCA) platform, analyzing the extent to which these initiatives contribute to achieving the SDGs. The research reveals that out of 72 initiatives examined, 71 contribute to 16 SDGs, with a strong focus on SDG 13 (Climate Action), SDG 9 (Industry, Innovation, and Infrastructure), SDG 7 (Affordable and Clean Energy), and SDG 12 (Responsible Consumption and Production). However, SDGs related to gender equality (SDG 5), health (SDG 3), and education (SDG 4) are scarcely addressed by these initiatives.

Laumann et al. (2022) investigates the intricate relationships between SDGs and climate change using a network analysis approach. By employing data from the World

Bank, covering 400 indicators from 2000 to 2019, and annual temperature data, the study examines how the 17 SDGs and climate change are interconnected. A key finding of the research is the central role of SDG 17 (Partnerships for the Goals) across many country groupings, highlighting its importance in promoting global collaboration and economic growth (SDG 8). The study also identifies a recurring nexus in developing countries, particularly between SDG 1 (Poverty Reduction), SDG 4 (Education), and SDG 8 (Economic Growth), with occasional links to SDG 5 (Gender Equality) and SDG 16 (Peace and Justice).

Song and Jang (2023) conducted a network analysis to explore the interlinkages between the SDGs using text-mining methods. Their study highlights that targets from different SDG goals often form interconnected communities, suggesting the need for inter-sectoral strategies rather than relying solely on the 17-goal framework. They found that most interlinkages between targets exhibit moderate strength, with stronger associations occurring within the same goal. The research emphasizes the importance for national and local governments to understand these interrelationships to develop effective policies.

Smith et al. (2023) explored the integration of health and sustainable SDGs using text mining and network science techniques. Analyzing 20 years of global research, they identified thematic interconnections between SDG 3 ("Good health and well-being") and other SDGs. The study revealed an increasing trend in integrating health with other SDGs, particularly with SDG 2 (Zero hunger), SDG 4 (Quality education), and SDG 11 (Sustainable cities and communities). The research underscores the potential of advanced analytical methods to enhance understanding and policymaking in sustainability science.

Bie et al. (2023) investigates the advancement of Arctic nations towards achieving SDGs. The study uses 69 indicators tailored to the unique challenges of Arctic countries, applying a composite index approach to assess their sustainability performance from 2000 to 2020. The analysis shows that overall progress in sustainable development has

improved, particularly for SDG 3 (Health and Well-being), SDG 4 (Quality Education), and SDG 10 (Reducing Inequality).

Asadullah et al. (2024) highlighted the need to address the hidden quality gaps that can help repair broken interlinkages between SDGs. The authors illustrated the disconnections between SDGs 4 and 5, they examined the issue of "education without employment" in South Asia. They suggested that a hidden form of gender inequality- namely, gender stereotypes in educational materials- may weaken the links between SDG targets in the region. If this gender inequality in education quality is ignored, merely increasing girls' enrollment will not restore the connection between SDGs 4 (Quality Education) and 5 (Gender Equality). Therefore, addressing these hidden gaps in the quality of public services should be a top priority in the second half of the SDG campaign.

The literature review reveals a significant gap in comprehensive research on the interlinkages between education (SDG 4) and other SDGs using advanced methodologies like social network analysis and text mining. While many studies have explored the connections between specific SDGs, these analyses have often been limited to a relatively small number of reports or documents. Significant progress has been made in mapping SDG interlinkages, yet there remains a clear need for research that specifically examines the role of education in achieving a broader spectrum of SDGs through modern analytical methods. Previous studies have frequently relied on traditional analytical approaches, lacking detailed analysis of large amounts of unstructured data.

3. The Proposed Methodology for Analyzing Education and SDG Interlinkages

To study the interlinkages between education and other SDGs, a set of flagship reports has been chosen. Produced by various UN organizations, these reports offer comprehensive and systematic coverage of key topics related to sustainable development. Recognized for their credibility, they are regularly updated to reflect the latest data and policy developments. These reports provide a rich and diverse set of

perspectives, reflecting the varied mandates and priorities of their respective organizations, and they provide a comprehensive overview of global challenges and opportunities, helping to inform and guide international policy and development efforts.

Analyzing these flagship reports ensures this study leverages high-quality information representative of the current global discourse on sustainable development. Additionally, these reports cover a broad spectrum of thematic areas, capturing the multifaceted links between education and the SDGs. This selection provides a robust foundation for analysis, enabling the drawing of meaningful insights and the formulation of informed recommendations.

To ensure comprehensive coverage, 78 flagship reports were selected from various UN agencies, including the World Bank, encompassing a broad range of related sustainable development topics. Appendix A provides a list of the reports. The focus is on global reports, excluding region-specific ones. Additionally, reports from non-UN entities (e.g., OECD) were not included. The selection offers a well-balanced mix of perspectives, featuring reports from UN agencies that emphasize social issues (such as UNESCO, UNDP, UNICEF, WHO, FAO, ILO, UNFPA, UN Women, UN-Habitat), those with a more economic focus (like the World Bank, UNIDO, WTO, UNCTAD), and others that highlight environmental concerns (including UNEP, CBD).

Vladimirova and Le Blanc (2016) analyzed a set of flagship reports to study the links between education and other SDGs. However, their methodology was mainly to search for the word "education" within each report using both traditional and manual methods, then, a small set of statements and paragraphs was extracted, forming the basic source file for further analysis. Each extracted statement and paragraph were manually linked to one or several of the thematic areas of the SDGs. For instance, statements like "education helps eradicate poverty" were linked to SDG 1 on poverty eradication. Some statements and paragraphs were linked to multiple SDGs, depending on their context.

The methodology of (Vladimirova and Le Blanc, 2016), while thorough, has several limitations, including being time-consuming and potentially subject to human error,

making it less suitable for analyzing a larger set of reports. To address these limitations, this study recommends employing social network analysis and text mining techniques.

Text mining can significantly enhance the efficiency and accuracy of analyzing a larger number of reports, potentially up to 78.

The proposed approach involves using automated text mining techniques based on Python programming to extract useful information from large unstructured text datasets. By employing these modern techniques, the analysis becomes more scalable and efficient, allowing for the examination of a larger number of reports with greater accuracy. This approach not only saves time but also enhances the reliability and comprehensiveness of the analysis, providing deeper insights into the interlinkages between education and other SDGs.

The methodology employed in this study involved a systematic and structured approach to data analysis, text mining, and bipartite network analysis. This comprehensive process aimed to uncover and categorize the prominent themes linking education to various SDGs. This methodological approach provided a comprehensive and detailed understanding of how education intersects with various SDGs, revealing distinct thematic focus areas and facilitating a deeper analysis of these interlinkages. The integration of bipartite network analysis with topic modeling enhanced the ability to visualize and interpret the complex relationships between education and SDGs. The findings from this analysis can inform policy making and the development of targeted educational interventions to support SD. The following steps outline the detailed methodology used:

1- Data Collection: The latest versions of 78 selected flagship reports were downloaded. These reports comprised approximately 1.6 GB of data, spanning 23,000 pages and containing about 12.8 million words.

2- Text Mining: A Python script was developed to extract statements and paragraphs containing the word "education" from these reports. This process involved

several stages of text preprocessing, including tokenization, removal of stop words, and elimination of numbers and irrelevant terms (Rabie, 2023).

3- Keyword Association: Each extracted statement was associated with one or more SDGs using a list of SDG-related keywords, from Table 1. This step facilitated the identification of relevant links between education and the goals (Rabie, 2022).

Table (1): SDG related keywords

Goal	Keywords
G1	basic needs, social safety nets, social protection, lowincome, vulnerability, vulnerable, poverty, poor
G2	Irrigation, nutrition, farmer, malnutrition, agriculture, food, hunger, agricultural, nutritious, crop
G3	deaths, births, vaccine, mortality, medicine, health, diseases, medical, infected, antenatal care
G5	empowerment, gender, women, girl, violence
G6	rivers, lakes, drinking, hygiene, sanitation, water, desalination, drought, flood, Irrigation
G7	electricity, renewable, energy, wind, solar, fuel, emission
G8	jobs, work, employment, GDP, labour, labor, economic, pay, economy, trade, tourism, unemployment
G9	internet, infrastructure, research and development, technolog, industr, innovation
G10	migration, discrimination, inequal, wage, equity, equality, human rights
G11	urban, cities, settlement, disaster, housing
G12	recycling, waste, Consum, produc, recycle
G13	desertification, forests, adaptation, mitigation, climate, greenhouse, temperature, pollution, cop, co2, carbon
G14	coastal, fish, ocean, marine
G15	biodiversity, ecosystem, forest, land, desertification
G16	weapon, judiciary, illegal, law, conflicts, terrorism, abuse, accountability, accountable, crime, governance, peace, justice, corruption

4- Data Preparation and Analysis: approximately 18,000 statements and paragraphs were extracted to study the interlinkages between education and other SDGs. It is important to note that a single statement can link education to multiple goals. For example, Next statement was counted five times because it connects education to five different SDGs: SDG 2 (Zero Hunger), SDG 3 (Good Health), SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation, and Infrastructure), and SDG 11 (Sustainable Cities and Communities).

"linkages between urbanization and access to affordable healthy diets are not unequivocal observations depend highly on local or national context specific dynamics including investments in agrifood systems as well as in rural and urban infrastructure training and education and economic policies" The State of Food Security and Nutrition in the World 2023.

5- Bipartite Network Analysis: The bipartite network structure enabled the identification of clusters and patterns within the data, enhancing the understanding of the links between education and sustainable development (Sciarra et al., 2021). A

bipartite network analysis was conducted to visually represent and analyze the connections between education-related statements and SDGs. In this network:

- One set of nodes represents the statements, while the other represents the SDGs.
- Edges between nodes indicated a link between a statement and an SDG, reflecting the thematic interconnection.
- This analysis provided insights into the strength and frequency of connections, revealing which SDGs were most frequently linked with education-related themes.

6- Text Mining and Topic Modeling: Text mining techniques are pivotal for extracting actionable insights from extensive volumes of unstructured text data. The process involves transforming raw text into structured formats that can be analyzed. Text mining helps uncover hidden patterns, trends, and relationships within the data. Text mining enables the identification of key topics, and the discovery of unrecognized connections between concepts (Rabie, 2023).

Among the various text mining techniques, topic modeling stands out as an effective method for identifying and summarizing latent themes (Rabie, 2023). Topic modeling works by analyzing the co-occurrence of words in a text corpus to uncover clusters of words that frequently appear together. These clusters are interpreted as topics that represent broader themes or concepts present in the documents. Unlike traditional keyword-based analysis, which focuses on specific words or phrases, topic modeling provides a more comprehensive view of the data by grouping related words into coherent topics. This approach is especially valuable when dealing with large datasets, where manual review and categorization would be too time-consuming. By using topic modeling, more insights can be gained about the topics within the text. For each SDG, Latent Dirichlet Allocation (LDA) was applied to identify the top three topics within the grouped statements. LDA is a probabilistic model that assumes documents (in this case, statements) are mixtures of topics, and topics are mixtures of words.

4. Results of Applying the Methodology using Flagship Reports

4-1 Links Between Education and SDGs Based on Flagship Reports

After extracting and identifying the statements and paragraphs linking education to various SDGs, we compiled a data file containing 18,085 statements and paragraphs. Table 2 presents the flagship report titles alongside the number of statements and paragraphs that reference each SDG category. Table 2 shows the following:

1- Most Referenced Reports:

- Global Education Monitoring Report: This report demonstrates the highest frequency of education-related references.
- Human Development Report: The second most referenced document indicates the significant emphasis on the role of education in human development.
- Climate Change Impacts, Adaptation, and Vulnerability Report: highlights the integral role of education in climate change discourse.

2- Most SDGs Referenced:

- SDG 8 (Decent Work and Economic Growth): This goal exhibits the highest number of references, reflecting the strong correlation between education and economic development.
- SDG 5 (Gender Equality): in the second rank, this SDG shows the significant integration of education in the context of gender equality.
- SDG 9 (Industry, Innovation, and Infrastructure): Ranking third, this goal highlights the critical importance of education in driving industry, innovation and infrastructural advancements.

The analysis highlights the interlinkages between education and other SDGs, particularly those related to economic growth, innovation, and gender equality. This insight can guide policymakers in identifying critical intersections where education can drive sustainable development, aiding in the prioritization of education-focused interventions in areas such as economic growth, health, and gender equality. By mapping the frequency of references to SDGs, it is evident that education serves as both an

independent goal and a crucial enabler for broader developmental outcomes. This table provides a valuable resource for stakeholders aiming to integrate educational strategies into their sustainable development initiatives, and highlights the important role of education in fostering sustainable development across multiple dimensions.

Table (2): Frequency of References to SDGs in Global Flagship Reports

Report	G1	G2	G3	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	G16	Total
Global education monitoring	386	64	213	872	154	151	1,530	1,137	978	182	158	229	107	457	543	7,161
Human development report	**117**	**25**	**298**	**240**	**55**	**28**	**270**	**93**	**344**	**31**	**45**	**61**	**3**	**84**	**45**	**1,739**
Climate Change Impacts, Adaptation and Vulnerability	91	110	102	58	103	30	116	74	55	85	33	237	46	79	52	1,271
Science Report	**12**	**95**	**129**	**52**	**37**	**73**	**293**	**352**	**19**	**29**	**31**	**34**	**10**	**38**	**33**	**1,237**
In action for gender equality	12		28	485	6	2	84	55	131	16	17	10	10	18	32	906
State of World Population	**18**	**5**	**210**	**274**	**4**	**3**	**81**	**3**	**52**	**7**	**95**	**6**		**28**	**45**	**831**
Global Environment Outlook - GEO 6	37	47	67	44	69	36	74	41	29	32	43	84	24	45	21	693
Climate Change Mitigation of Climate Change	**20**	**22**	**43**	**14**	**11**	**52**	**60**	**41**	**15**	**15**	**29**	**53**		**7**	**10**	**392**
The State Of Food Security And Nutrition In The World	34	112	35	27	13	2	33	10	21	32	28	3	4	8	3	365
World Development Report	**22**	**8**	**60**	**26**	**2**	**2**	**138**	**20**	**32**	**10**	**15**	**1**		**6**	**9**	**351**
The State of the World's Children	40	20	71	41	11		73		10	2	1			28	16	313
World Investment Report	**1**	**57**	**44**	**6**	**40**	**49**	**17**	**45**	**4**	**3**	**10**	**10**	**2**	**9**	**3**	**300**
World Water Development Report	1	12	18	21	68	9	29	25	7	9	5	12	1	12	18	247
Progress of the World's Women	**8**	**7**	**34**	**83**	**1**		**54**	**5**	**21**		**10**			**3**	**8**	**234**
Education Finance Watch	45	2	7	2		2	115	2	22	3	16	1		7	8	232
The Sustainable Development Goals Report	**28**	**8**	**19**	**17**	**11**	**9**	**47**	**16**	**12**	**3**	**8**	**11**	**8**	**6**	**9**	**212**
World report on the health of refugees and migrants	16	5	58	27	10		33	2	10	11	3			7	6	188
World employment and social outlook trends	**10**	**3**	**13**	**7**	**2**	**3**	**94**	**11**	**6**	**1**	**21**	**1**		**1**	**1**	**174**
The state of food and agriculture	16	29	5	20	7	1	38	11	5	8	10	5		5		160
World Social Protection Report	**18**	**14**	**17**	**10**	**5**		**36**	**1**	**10**	**4**	**5**	**3**			**3**	**126**
World Trade Report	11	3	15	7	4	7	29	15	9	8	5	8	2	2	1	126
Global Assessment Report on Disaster Risk Reduction	**7**	**8**	**14**	**9**	**8**	**4**	**14**	**8**	**4**	**5**	**5**	**10**		**4**	**4**	**104**
Global Resource Outlook	1	8	6	1	12	13	7	1	20	1	2	9		12		93
Global Wage Report	**3**	**11**	**13**	**9**	**1**	**3**	**25**		**12**	**9**	**3**			**3**		**92**
world health statistics	7	3	16	5		1	24		18	8	1					83
Results in Education for All Children	**10**		**5**	**1**			**26**	**10**	**3**		**17**	**4**			**5**	**81**
Digital Progress and Trends Report	4	4	24	7		1	6	10			1	1				58
Trade and Development Report	**3**	**7**	**14**		**2**	**3**	**11**	**3**	**1**	**2**	**4**	**5**	**1**	**1**	**1**	**58**
IFC Annual Report	1	2	8				7	18	4		5	2		7		54
Global Biodiversity Outlook 5		**10**	**2**	**3**	**6**		**5**	**4**	**1**	**1**		**4**	**6**	**9**		**51**
Plant Production and Protection		10			3		2	5	2		2	1		5		30
World Energy Outlook	**1**		**2**	**1**		**6**	**11**	**3**			**2**	**2**	**1**			**29**
Industrial Development Report			2			1	4	8		2	2	2				21
Digital economy report		**1**	**4**	**1**		**2**	**7**	**3**			**1**			**1**		**20**
PROBLUE Annual Report				5			7				2	1	3	1		19
Human Settlement Programme			**2**	**1**	**1**		**2**			**4**		**1**				**11**
Sixth Assessment Report	3	2		2		1		1				1				10
PROGREEN Annual Report		**1**	**1**	**1**			**2**					**1**		**1**		**7**
global waste management outlook	1		2				1				2					6
Total	**984**	**715**	**1,601**	**2,379**	**646**	**494**	**3,405**	**2,033**	**1,857**	**523**	**637**	**813**	**228**	**894**	**876**	**18,085**

4-2 Analysis of the Bipartite Network of the interlinkages of Education in Flagship Reports

In analyzing the presence and distribution of education-related references across various flagship reports and their relevance to the SDGs, bipartite network graphs emerge as a powerful and effective visualization tool. This analysis encompasses a dataset of 18,085 statements and paragraphs from different reports. Bipartite networks are very useful in representing the complex relationships between two distinct sets of entities—in this study, the flagship reports and the SDGs. Each report and SDG is represented as a node, with edges denoting the presence of references to education within

the context of specific SDGs. This structure allows for a straightforward visual representation of which reports emphasize which SDGs, making it easier to discern patterns and connections that might be less apparent in tabular or textual formats.

As a social network analysis tool, Bipartite graphs can provide a clear and intuitive visualization of the relationships between flagship reports and SDGs, highlighting key patterns and connections that are essential for stakeholders and policymakers. The ability to represent complex relationships, highlight key connections, and derive actionable insights makes bipartite graphs an invaluable tool in the analysis and visualization of educational references in the context of sustainable development. By leveraging this approach, stakeholders can better understand the pivotal role of education in fostering sustainable development across multiple dimensions and effectively integrate educational strategies into their initiatives.

To create a bipartite network for these relationships, "R-nodes" are used to represent the reports as one set of nodes and the "G-Nodes" to represent SDGs, as the other set of nodes. The connections between them would represent which R-nodes "reports" covers which G-Nodes "SDGs". The components of the bipartite network:

1- Node sets: As shown in Figure 1

- Set 1: R-Nodes (e.g., "Global education monitoring", "Human development report", etc.).
- Set 2: G-Nodes (G1, G2, G3, G5, G6, …, G16).

2- Links: Create a link between R-node and G-Node, if the report covers that SDG.

Figure 1 shows the bipartite network which visualizes the relationship between flagship reports and the SDGs they cover.

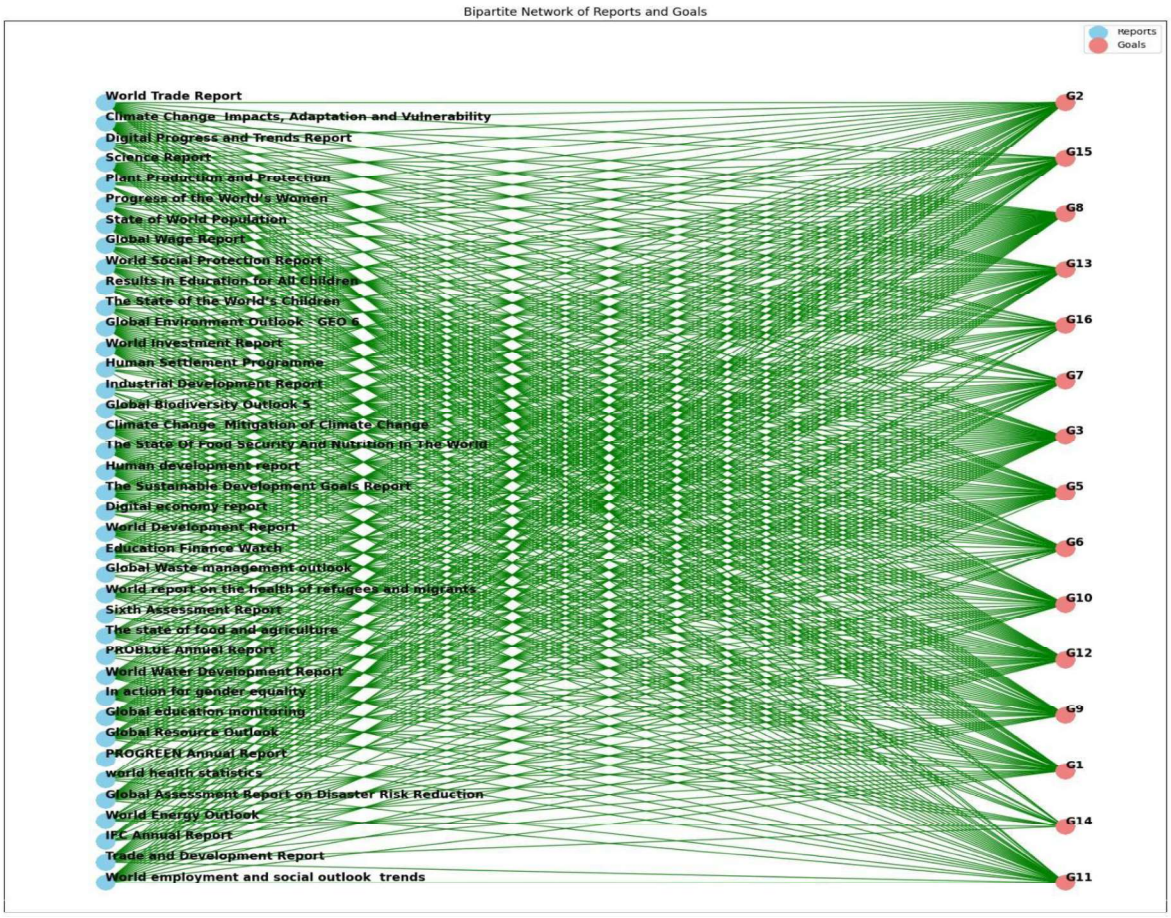

Figure (1): Bipartite network of flagship reports and SDGs

Converting the Bipartite Network to Two Projected Networks

To gain deeper insights into the relationships from the bipartite network in Figure 1, the network can be projected into two distinct one-mode networks: one representing the relationships among reports based on shared SDGs, and the other representing the relationships among SDGs based on the reports that reference them. This approach helps to analyze the structure and significance of these connections in detail.

Steps to Analyze the Bipartite Projected Networks:

1- Projecting the Bipartite Graph:

By projecting the bipartite graph, two new graphs are created:

- SDG-SDG Network: Nodes represent SDGs (G-nodes), and edges are weighted by the number of reports that reference both SDGs.

- Report-Report Network: Nodes represent reports (R-nodes), and edges are weighted by the number of SDGs that both reports reference.

2- Calculating Edge Weights:

The weight of a link in each projected network represents the strength of the relationship between two nodes. In the SDG-SDG network, it indicates how many reports reference both SDGs. In the Report-Report network, it shows how many SDGs two reports have in common.

3- Analyzing the SDG-SDG Network

Figure 2 shows the SDG-SDG network graph illustrates the interconnections between different SDGs based on the analysis of education-related references within flagship reports. Each node represents a specific SDG, and the edges indicate the presence of overlapping references to education, showcasing how various goals are interconnected through their educational components.

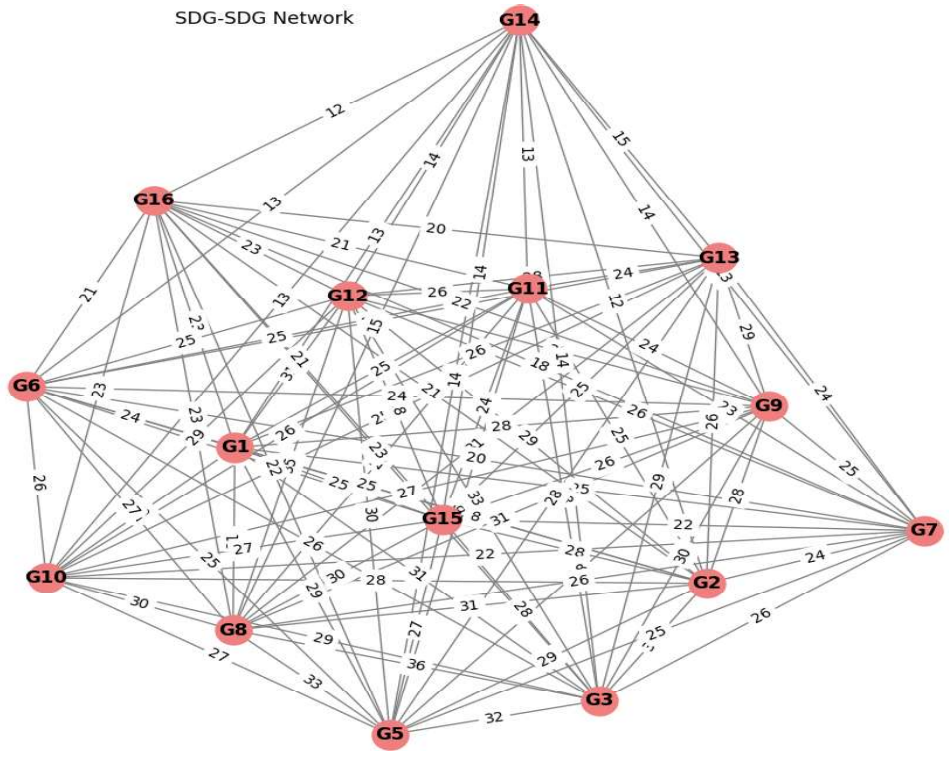

Figure (2): SDG-SDG Network

To facilitate a clearer interpretation of the network in Figure 2, a heat map (Figure 3) has been generated. This heat map illustrates the linkages between different SDGs along with their respective weights. The intensity of the color and the numerical values in each cell represent the strength of the linkage between two SDGs. Figure 3 shows the following:

1- Strongest linkages:

- Goal 3 (Good Health and Well-being) and Goal 8 (Decent Work and Economic Growth) - 36
- Goal 8 (Decent Work and Economic Growth) and Goal 12 (Responsible Consumption and Production) - 35
- Goal 3 (Good Health and Well-being) and Goal 12 (Responsible Consumption and Production) - 33
- Goal 5 (Gender Equality) and Goal 8 (Decent Work and Economic Growth) - 33
- These strong linkages suggest that improvements in economic conditions and work environments (Goal 8) are closely tied to health outcomes (Goal 3), sustainable resource use (Goal 12), and gender equality (Goal 5).

2- Goal 8 (Decent Work and Economic Growth) appears to be a central node, having strong connections with many other goals. This underscores the importance of economic factors in achieving other sustainable development objectives.

3- Goal 14 (Life Below Water) has the weakest overall connections. This might indicate that marine conservation efforts are somewhat isolated from other development goals, potentially requiring more integrated approaches.

4- Goals with strong overall connections: Goal 1 (No Poverty), Goal 3 (Good Health and Well-being), Goal 5 (Gender Equality), Goal 8 (Decent Work and Economic Growth) and Goal 12 (Responsible Consumption and Production), these goals seem to be key drivers or beneficiaries of progress across multiple SDGs.

5- Goal Clusters:

- Social goals (1, 3, 4, 5) are closely interlinked.

- Economic and production goals (8, 9, 12) form another tight cluster.
- Environmental goals (13, 14, 15) show moderate interconnections.

The analysis of the heatmap reveals the complex web of relationships between the SDGs, highlighting the importance of integrated, holistic approaches to development over isolated efforts on single goals. The central role of economic factors (Goal 8) indicates that sustainable economic development could be a powerful lever for progress across multiple dimensions of sustainable development. The network suggests that the SDGs are highly interconnected, with some goals playing central roles in the overall framework. It underscores the necessity of considering these relationships when working towards achieving the SDGs, as progress in one area is likely to impact others.

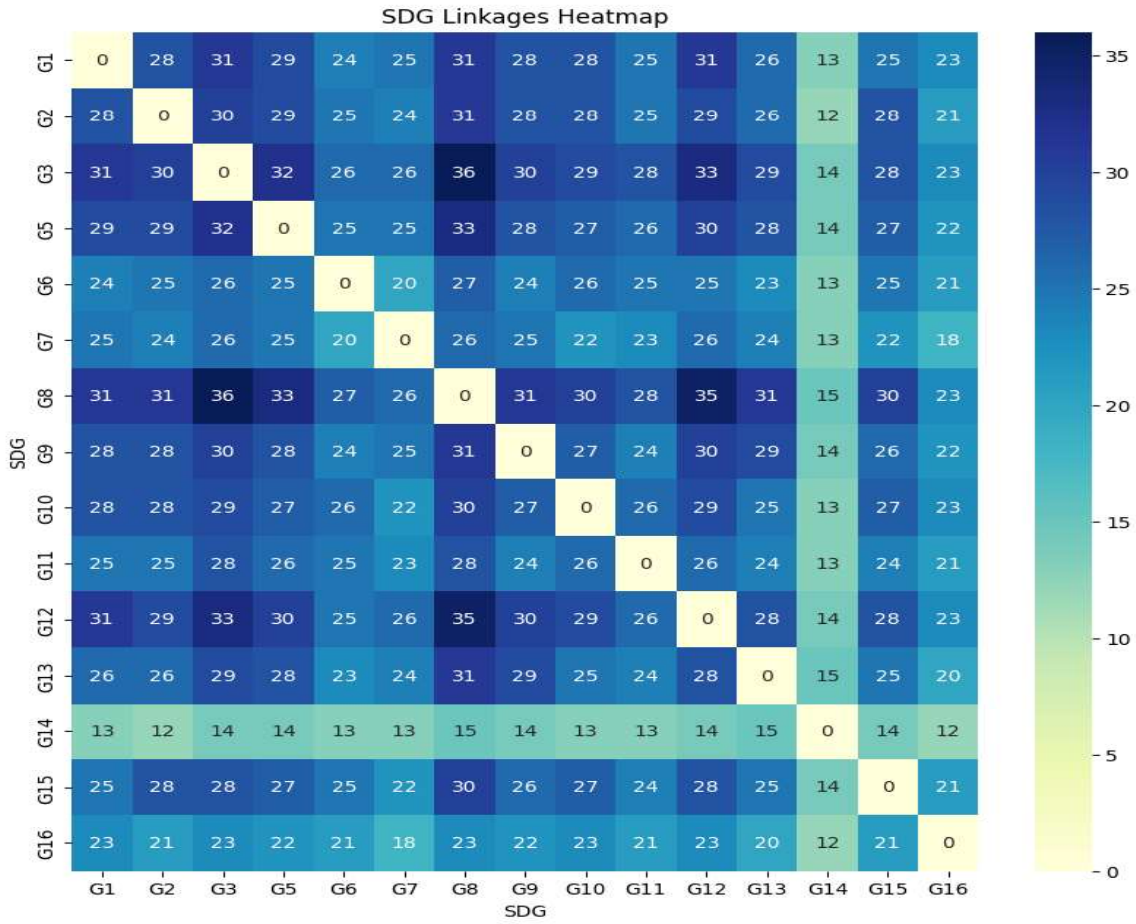

Figure (3): SDG linkages Heat map

4-3 Topic Modeling for SDGs: Analyzing Key Themes and Insights

This section uses topic modeling to analyze SDG-related text data. Topic modeling uncovers hidden thematic structures within large document collections, identifying relevant topics for each SDG and highlighting key focus areas. As an unsupervised machine learning technique, it clusters frequently co-occurring words into topics, representing underlying themes. Latent Dirichlet Allocation (LDA) is a common method, assuming documents are mixtures of topics and topics are mixtures of words. LDA helps extract dominant topics and associated keywords, providing a clearer understanding of the main themes (Rabie, 2023).

Table 3 identifies the top three topics for each SDG, highlighting significant keywords. The analysis reveals distinct thematic areas, emphasizing the interconnected nature of sustainable development and education's critical role. These insights guide policymakers and stakeholders in developing targeted strategies to leverage education for advancing sustainable development across various dimensions, promoting a more equitable, inclusive, and sustainable future.

For SDG 1 (No Poverty), the primary themes revolve around economic development, social protection, and health, highlighting the need for inclusive policies that support the poorest and most vulnerable populations. SDG 2 (Zero Hunger) emphasizes the importance of sustainable agricultural practices, climate resilience, and access to nutritious food, indicating a comprehensive approach to ending hunger and malnutrition.

SDG 3 (Good Health and Well-being) focuses on reproductive health, global health policies, and access to healthcare services, underlining the necessity of robust health systems and international cooperation. SDG 5 (Gender Equality) highlights issues of women's empowerment, gender equality, and access to education, emphasizing the critical role of gender-responsive policies in achieving sustainable development.

SDG 6 (Clean Water and Sanitation) and SDG 7 (Affordable and Clean Energy) both stress the importance of sustainable resource management, access to clean water and energy, and the integration of climate action into development strategies. SDG 8 (Decent

Work and Economic Growth) points to the need for skills development, employment policies, and economic inclusion to foster sustainable economic growth. SDG 9 (Industry, Innovation, and Infrastructure) focuses on technological advancement, innovation, and infrastructure development, underscoring the role of education in promoting industrialization and innovation. SDG 10 (Reduced Inequality) addresses issues of income inequality, social equity, and human development, advocating for policies that promote inclusivity and fairness.

SDG 11 (Sustainable Cities and Communities) and SDG 12 (Responsible Consumption and Production) emphasize urban development, disaster management, and sustainable consumption practices, highlighting the interconnectedness of urbanization and sustainability. SDG 13 (Climate Action) underscores the urgent need for climate adaptation, risk management, and sustainable development practices to mitigate the impacts of climate change. SDG 14 (Life Below Water) and SDG 15 (Life on Land) focus on the conservation of marine and terrestrial ecosystems, sustainable management of natural resources, and climate resilience, indicating the critical importance of environmental sustainability. Lastly, SDG 16 (Peace, Justice, and Strong Institutions) highlights issues of governance, justice, human rights, and sustainable development, stressing the need for strong institutions and effective governance frameworks.

Table 3: Key Themes and Focus Areas Identified Through Topic Modeling for Each SDG

Goal	Topic	Keywords	Focus Area
G1	Topic 1	poorest, lower, asia, development, children, secondary, income, countries	Poverty and Education
	Topic 2	poorer, lowincome, social, spending, total, poor, health, poverty, countries	Social and Economic Inequalities
	Topic 3	republic, poverty, food, access, protection, human, health, development, social, sdg	Health and Social Protection
G2	Topic 1	services, climate, access, management, energy, health, water, food, sdg	Climate and Resource Management
	Topic 2	protection, environmental, , nutrition, international, health, development, global, food	Environmental and Nutritional Health
	Topic 3	institute, technology, science, development, agriculture, international, research, university	Agriculture and Technology
G3	Topic 1	human, reproductive, aged, development, married, ages, republic, sdg, health, women	Reproductive Health and Development
	Topic 2	international, primary, income, , human, global, social, countries, development, health	Global Health and Development
	Topic 3	development, energy, percent, food, access, water, social, services, sdg, health	Energy and Water Access
G5	Topic 1	index, countries, net, women, lower, republic, enrolment, rate, secondary	Education and Gender Equality
	Topic 2	social, unesco, health, womens, countries, access, equality, girls, women, gender	Health and Gender Equality
	Topic 3	income, sustainable, percent, women, human, report, global, gender, development, sdg	Global Gender Development
G6	Topic 1	food, sustainable, climate, energy, sanitation, access, management, health, water, sdg	Water and Sanitation
	Topic 2	student, asia, sporadic, development, students, low, basic, schools, medium, high	Education Quality and Access
	Topic 3	, health, percent, countries, water, nations, global, development, international, united	International Development and Health
G7	Topic 1	global, renewable, water, sustainable, total, development, health, international, energy	Renewable Energy and Health
	Topic 2	development, management, access, sustainable, climate, food, countries, water, energy, sdg	Sustainable Resource Management
	Topic 3	basic, schools, trends, development, medium, high	Education and Development
G8	Topic 1	human, water, work, sustainable, access, social, economic, development, health, sdg	Economic Development and Health
	Topic 2	global, human, , medium, republic, sdg, secondary, primary, development, high	Education and Development
	Topic 3	share, public, skills, employment, research, higher, policy, training, countries	Skills and Employment
G9	Topic 1	energy, information, water, learning, countries, global, infrastructure, technology, sdg	Infrastructure and Technology
	Topic 2	asia, , basic, international, low, sdg, schools, development, medium, high	Education and Development
	Topic 3	, higher, policy, ministry, development, science, research, innovation, technology	Research and Innovation
G10	Topic 1	low, hdi, republic, value, countries, sdg, income, inequality, human, development	Income and Inequality
	Topic 2	index, high, countries, nations, development, human, international, , inequality	Global Development and Inequality
	Topic 3	development, health, equity, rights, social, countries, access, global, equality, gender	Health and Social Equity
G11	Topic 1	areas, disaster, development, digital, women, access, urban, countries,	Urban Development and Health
	Topic 2	training, development, percent, global, countries, primary, secondary, level	Global Education Levels
	Topic 3	areas, energy, housing, management, food, climate, water, urban, health, sdg	Climate and Urban Health
G12	Topic 1	production, management, health, climate, energy, water, consumption, food, sustainable, sdg	Sustainable Consumption and Health
	Topic 2	national, products, countries, health, social, technology, international, global, development	Global Technology and Development
	Topic 3	net, percent, sdg, republic, aged, rate, sexual, reproductive, women, health	Health and Reproduction
G13	Topic 1	water, asia, youth, secondary, africa, development, , adults, global, international	Climate and Education
	Topic 2	risk, development, health, management, water, access, adaptation, change, climate	Climate Risk Management
	Topic 3	food, action, areas, investment, water, climate, development, energy, sustainable, sdg	Climate Action and Sustainability
G14	Topic 1	change, food, marine, climate, energy, management, sustainable, land, water, sdg	Marine and Climate Sustainability
	Topic 2	middle, africa, lower, income, primary, northern, america, secondary, asia	Education and Income Levels
	Topic 3	america, expenditure, low, total, new, gdp, region, high, medium	Economic Expenditure and Regions
G15	Topic 1	country, upper, republic, tertiary, rate, lower, islands, primary, secondary, yes	Education Levels and Rates
	Topic 2	low, states, sdg, human, countries, , development, republic, medium, high	Global Development and Equality
	Topic 3	sustainable, food, development, energy, management, climate, land, water, sdg	Sustainable Land Management
G16	Topic 1	rights, laws, national, human, gender, , global, development, countries	Rights and Development
	Topic 2	africa, women, asia, south, health, guinea, development, countries	Health and Regional Development
	Topic 3	law, chapter, public, justice, change, sustainable, water, climate, governance, sdg	Law and Governance

Summary and Conclusion for Future Work

Studying the interlinkage between education and other SDGs is crucial for achieving holistic progress and is essential for sustainable development planning. This study's comprehensive analysis of the interlinkages reveals the complex and multifaceted nature of sustainable development. By using advanced text mining techniques and network analysis, the study provides deeper insights into how education intersects with and influences various aspects of sustainable development.

Key findings include the strong connections between education and goals related to economic growth, gender equality, and innovation. The centrality of SDG 8 (Decent Work and Economic Growth) in the SDG-SDG network highlights the critical role of economic factors in achieving sustainable development. The identification of goal clusters, such as social goals (1, 3, 4, 5) and economic and production goals (8, 9, 12), highlights the interconnected nature of the SDGs and the need for holistic approaches.

Topic modeling results further clarify the specific focus areas within each SDG, ranging from poverty reduction and gender empowerment to climate action and environmental conservation. These insights demonstrate the diverse ways in which education can contribute to and enhance progress across multiple SDGs.

The study's findings have significant implications for policymaking and program development. They emphasize the need for integrated, cross-sectoral approaches that recognize and leverage the synergies between education and other development goals. Policymakers and stakeholders should consider these interlinkages when designing interventions, ensuring that educational strategies are embedded within broader sustainable development efforts.

Future research could build on this work by exploring the temporal dynamics of these interlinkages, analyzing how they evolve over time, and investigating the practical implementation of integrated strategies in various contexts. Additionally, expanding the analysis to include a broader range of documents and data sources could further enrich the understanding of the role of education in sustainable development.

In conclusion, this research provides a robust foundation for understanding the pivotal role of education in achieving the SDGs. By highlighting the complex web of relationships between education and other sustainable development goals, it highlights the importance of holistic, integrated approaches to addressing global challenges and advancing sustainable development for all.

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Appendix A:

#	Report Name	#	Report Name
1	Climate Change 2022 Impacts, Adaptation and Vulnerability	40	State of World Population 2022
2	**Climate Change 2022 Mitigation of Climate Change**	41	**State of World Population 2023**
3	Digital economy report 2019	42	State of World Population 2024
4	**Digital Progress and Trends Report 2023**	43	**The state of food and agriculture 2021**
5	Education Finance Watch 2022	44	The state of food and agriculture 2022
6	**Education Finance Watch 2023**	45	**The state of food and agriculture 2023**
7	Global Assessment Report on Disaster Risk Reduction 2022	46	The State Of Food Security And Nutrition In The World 2021
8	**Global Assessment Report on Disaster Risk Reduction 2023**	47	**The State of Food Security and Nutrition in the World 2022**
9	Global Biodiversity Outlook 5 2020	48	The State of Food Security and Nutrition in the World 2023
10	**Global education monitoring 2019**	49	**The State of the World's Children 2021**
11	Global education monitoring 2020	50	The State of the World's Children 2023
12	**Global education monitoring 2021**	51	**The Sustainable Development Goals Report 2021**
13	Global education monitoring 2022	52	The Sustainable Development Goals Report 2022
14	**Global education monitoring 2023**	53	**The Sustainable Development Goals Report 2023**
15	Global Environment Outlook - GEO 6 2019	54	Trade and Development Report 2021
16	**Global Resource Outlook 2024**	55	**Trade and Development Report 2023**
17	Global Wage Report 2020 2021	56	World Development Report 2021
18	**Global Wage Report 2022 2023**	57	**World Development Report 2022**
19	global waste management outlook 2024	58	World Development Report 2023
20	**Human development report 2019**	59	**World employment and social outlook trends 2021**
21	Human development report 2020	60	World employment and social outlook trends 2022
22	**Human development report 2021**	61	**World employment and social outlook trends 2023**
23	Human development report 2023	62	World Energy Outlook 2021
24	**Human Settlement Programme 2021**	63	**World Energy Outlook 2022**
25	Human Settlement Programme 2022	64	World Energy Outlook 2023
26	**IFC Annual Report 2022**	65	**world health statistics 2021**
27	IFC Annual Report 2023	66	world health statistics 2022
28	**In action for gender equality 2020-2021**	67	**world health statistics 2023**
29	In action for gender equality 2022-2023	68	World Investment Report 2021
30	**Industrial Development Report 2022**	69	**World Investment Report 2022**
31	Plant Production and Protection 2021	70	World Investment Report 2023
32	**Plant Production and Protection 2022**	71	**World report on the health of refugees and migrants 2022**
33	PROBLUE Annual Report 2022	72	World Social Protection Report 2020-22
34	**PROBLUE Annual Report 2023**	73	**World Trade Report 2021**
35	PROGREEN Annual Report 2023	74	World Trade Report 2022
36	**Progress of the World's Women 2019 2020**	75	**World Trade Report 2023**
37	Results in Education for All Children 2020	76	World Water Development Report 2022
38	**Science Report 2021**	77	**World Water Development Report 2023**
39	SIXTH ASSESSMENT REPORT 2022	78	World Water Development Report 2024