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Challenges in Attaining Sustainable Development Goals Between Income Groups: A Systematic Comparative Analysis

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Abstract: Achieving the Sustainable Development Goals (SDG) presents distinct challenges across different income economies, necessitating a comprehensive analysis to identify critical factors influencing progress. This study systematically examines obstacles to SDG attainment across various income groups by analyzing data from 215 nations spanning 2012 to 2021. Principal Component Analysis (PCA) was employed to uncover patterns within the factors, while fuzzy graph modeling elucidated their dynamic influences. The analysis focused on nine key variables: poverty, unemployment, youth literacy, adult literacy, health (undernourishment), food security, access to electricity, carbon dioxide (CO_2) emissions, and other greenhouse gas emissions. Findings indicate that CO_2 emissions serve as the primary barrier to achieving SDG 13 (climate action) in high-income nations. Conversely, poverty and undernourishment emerge as significant challenges impeding progress in upper-middle-income, lower-middle-income, and low-income groups. The study provides a novel, integrated view of the multifaceted impacts and interactions between socio-economic and environmental factors in addressing SDG challenges. The results offer valuable insights for policymakers, highlighting the need for differentiated strategies tailored to income-specific contexts. It is recommended that governments in high-income countries extend financial support to lower-income groups to alleviate poverty and improve food security, while fostering collaboration in climate mitigation and adaptation to promote balanced and sustainable global development.

Keywords: Fuzzy graph; Principal Component Analysis (PCA); Income groups; Poverty; Sustainable Development Goals (SDG)

1. Introduction

This study aims to identify the significant factors influencing SDGs attainment across different income groups using PCA and fuzzy graph techniques. Several nations appear to have made slow progress to meet the SDGs agenda by 2030, due to social and economic status (Akhtar-Schuster et al., 2024). According to Ukaogo et al. (2020), different countries have distinct challenges in attaining SDGs, depending on their social and economic status, as well as geographical and environmental conditions. Thus, in this paper, the dynamic significance of the determinants and challenges in attaining SDGs are identified in accordance with the income groups of a country.

The United Nations established 17 SDGs in 2015 that steer humanity towards a more sustainable path to reduce poverty, hunger, inequality, environmental degradation, enhance access to education and healthcare, and establish an egalitarian society (United Nations, 2015). The SDGs are a call to action for all nations, including those with low, middle, and high incomes, to advance prosperity while preserving the environment. These nations are moving towards attaining the 17 goals of the SDGs by implementing various policies and actions, as well as ensuring proper governance and coordination mechanisms across agencies and industries. Concerns about the significance and impact of each pillar have also grown in recent years, particularly as environmental quality has declined as a

result of economic activity (Baloch et al., 2020). Thus, the progress of the different countries may differ depending on their social, economic, and environmental conditions.

Poverty is one of the major obstacles in achieving the SDG. Poverty particularly hit hard after the COVID-19 phenomenon with 659 million people living in extreme poverty as of March 2023 (Baah et al., 2023). Poverty causes an increase in unemployment, impeding economic progress (Sutanto et al., 2024). Poverty and income inequality are the major socially driven elements that lead to other concerning issues, which are health, food, and nutrition security (Rehman et al., 2022). Poverty reduction is one of the most significant development goals for all countries, regardless of their income groups. Environmental issues such as greenhouse effects are also one of the critical challenges in attaining SDG, particularly SDG 13 (Climate Action). The greenhouse gases, including CO_2, methane, chlorofluorocarbons, and nitrous oxide, are released into the atmosphere mainly from human activities such as industrialization, transportation, and agriculture (Kabir et al., 2023). Developed and developing countries often have significant relationships with the release of greenhouse gases, particularly CO_2, due to rapid urbanization and high energy consumption (Ukaogo et al., 2020). High energy demand and rapid economic growth are major contributing factors to CO_2 emissions, which lead to bigger environmental issues and affect the progress of attaining the SDGs, particularly in countries with high-income economies (Ukaogo et al., 2020).

The World Bank categorizes the world's economies into four income groups: low-income, lower-middle-income, upper-middle-income, and high-income groups (Hamadeh et al., 2023). The categories are divided depending on the Gross National Income (GNI) per capita of the previous calendar year, and the GNI measures are expressed in US dollars (Hamadeh et al., 2023). High-income economies have a GNI per capita of more than $13,845 in 2022, upper-middle-income economies are those in which 2022 GNI per capita is between $4,466 and $13,845, lower-middle-income economies are those in which 2022 GNI per capita is between $1,136 and $4,465, and low-income economies are those in which 2022 GNI per capita is $1,135 or less (World Bank, 2023). The four income groups have different socio-economic statuses and they experience different limitations and outcomes concerning SDG. According to Cheng et al. (2021), global cooperation is crucial to achieving balance and sustainable global development. In particular, high-income groups play important roles in providing financial and economic support to low and middle-income groups, and thus they have to strengthen their economies, as well as financial and climate mitigation strategies (Cheng et al., 2021). Hence, analysis in identifying the most significant determinants and causes affecting a country's potential in meeting the SDGs are needed, particularly countries of different income groups, to address specific challenges and issues, thus enhancing more targeted strategies for balance and sustainable global development.

Numerous studies have applied statistical methods and assessment models to analyze the factors, challenges, and progress of different countries and regions in attaining the SDG. Hossin et al. (2023) utilized principal component regression (PCR) and forecasting models to analyze the progress of China and countries worldwide in attaining SDG 7 and SDG 13. Liu (2020), Cling & Delecourt (2022) and Hossin et al. (2024) analyze the progress of SDG on different income groups using Pearson Correlation, Hierarchical Cluster Analysis (HCA) and panel analysis (Generalized Method of Moments), respectively. Meanwhile, Drastichová & Filzmoser (2019), Cling et al. (2020), and Yin et al. (2023) applied PCA to analyze the performance of different income groups' countries, by categorizing them into several groups, and moreover, the factors influencing the progress of the SDG are identified based on their variation in SDG axes in the PCA biplot. These studies utilized statistical and assessment tools to determine the progress and challenges of different income groups in attaining the SDG. However, the previous analyses are lacking in terms of handling the inconsistent and missing longitudinal data. Besides, the significance of each factor is unexplored in prior research, which is crucial in identifying the importance of each factor, for more strategic mitigation and planning in attaining SDGs. Therefore, this study fills the gap by assessing the challenges and progress of income groups in achieving SDGs through the use of PCA and the dynamic significance of each factor is identified using a fuzzy graph approach, namely the fuzzy autocatalytic set (FACS) algorithm. This study aims to answer the following questions: How to model the multiple SDG indicators of different income groups using a fuzzy graph method for dynamic identification of factors? What are the key factors influencing the disparities in progress among low, lower-middle, upper-middle-, and higher-income groups towards SDG achievement? To what extent do these variables have a dynamic interrelationship with each other?

This study methodologically contributes to the literature by employing the fuzzy graph method, which is more robust in identifying the dynamic significance of factors that influence income groups to meet the SDGs. The identification of the significance and importance of each factor allows governments and policymakers to address the most important areas that need to be improved, and reallocate resources from low-impact factors to focus on the most crucial issues. Additionally, the findings of this study expand the body of knowledge on the complex interplay between socio-economic status and environmental factors, encouraging integrated strategies for policy-makers to address economic and social determinants to effectively reduce social issues.

2. Literature Review

2.1 Overview of PCA and Fuzzy Graph

PCA is an established statistical method that is widely used in cluster and classification analysis. The PCA is a projection method that transfers observations in the form of a scatter plot. Numerous researchers have utilized the PCA for data visualization, particularly to categorize samples or variables into several clusters in the PCA score plot. Recently, research on SDGs has become a key topic worldwide. Drastichová & Filzmoser (2019) and Cling et al. (2020) employ PCA to categorize European Union (EU) countries into several clusters based on their performance and progress of SDG attainment. Their results reveal that northern countries, which are developed countries, are the best-performing countries in attaining the SDGs as compared to other EU countries. Yin et al. (2023) utilized the PCA to identify the major axes of the SDGs for different income countries. Their results reveal that higher income countries show major progress for SDGs 2, 6, 7, 14, and 15. These researchers are able to classify countries into several clusters according to their progress in attaining the SDGs, using the PCA method, and identify the SDGs that are mapped to different income groups. In this study, the PCA technique is implemented in analyzing the pattern of income groups in attaining SDGs, in combination with a fuzzy graph method for further analysis and verification of the dynamic significance of the factors and challenges, which is lacking and unexplored in previous research.

The fuzzy graph is a mathematical method that could handle uncertainties, and model the dataset in the form of a dynamic graph for the identification of significant variables. The fuzzy graph method is a combination of fuzzy set and graph theory concepts. The fuzzy graph was first introduced in 2010 by Ahmad et al. (2010) for analysis of the waste incineration process. As a result, the most significant combustion product from the incineration process was successfully identified. Hassan et al. (2020) then introduced a fuzzy graph algorithm, namely the chemometrics fuzzy autocatalytic set (c-FACS), for the analysis of halal authentication of gelatin, and their results revealed the most significant pattern that distinguishes between halal and non-halal gelatin. Later, Hassan et al. (2021) utilized the algorithm to identify the dynamic pattern of the coronavirus disease 2019 (COVID-19) outbreak in Malaysia. As a result, the states with the most significant and critical COVID-19 cases were identified, as well as patterns of cases before and after mitigation strategies. Thus, the fuzzy graph method was able to model and identify dynamic patterns and the significance of variables in applications related to chemistry and health science. However, the algorithm has never been used to identify its dynamic significance in the areas of social science and economics. In this study, the fuzzy graph algorithm is modified and generalized as a FACS algorithm. The algorithm is used for modeling the SDG factors in the form of a fuzzy graph, and the graph is further analyzed for identification of the dynamic significance of factors in attaining the SDGs among different income groups.

2.2 Theoretical Underpinnings

Previous research explored the economy, environment, and sustainability using different types of theories. For instance, Abdulai & Shamshiry (2014) use the Theory of Economic, Political, and Social Distortions and claim bigger socio-economic problems are the primary cause of poverty owing to capitalism and the economy's structure, regardless of individuals' hard work, skills, and competencies. Davis & Sanchez-Martinez (2015) accentuated this imbalance in talent, skills, competence, and income, causing a poverty gap in a market-based, competitive economic system. These interrelationships between economy, environment, and sustainability are further explored using the Environmental Kuznets Curve (EKC), whereby environmental degradation and income have an inverted U-shaped relationship, and as economic development progresses, income inequality rises at first and subsequently diminishes (Kuznets, 1955). However, literature explores this EKC model and suggests that there exists a relationship among energy use, economic growth, and the environment where economic growth and technological changes affect environmental quality, and pollution issues are being addressed and resolved in developing economies as compared to rapidly growing income countries (Stern, 2004; Stern, 2018). The research on the EKC reveals that national environmental policies differ between high- and low-income nations and that pollution occurs as a result of income growth (Smulders, 2004). This assertion on the effects of disparities in environmental regulation stringency is known as the Pollution Haven hypothesis. According to this hypothesis, industrial countries will continue to be the primary polluters in the most polluting industries because they are capital-intensive, have access to large consumer markets, have qualified labor capable of running advanced technologies, and have political stability (Smulders, 2004). Previous literature highlights the importance of regulation for pollution-intensive industries to prevent the relocation of pollution damage from advanced nations with strict environmental laws into less developed countries with lenient environmental rules (Leal et al., 2021). Recent studies by Ozturk et al. (2023) and Wang et al. (2024) bridge the EKC and Pollution Haven hypotheses, as both explained that environmental changes are due to economic expansion and the U-shaped curve is highlighted between economic growth and environmental degradation. These studies mainly focus on unveiling concepts related to the economy, environment, and sustainability but lack a comprehensive assessment of SDG

measurement. Therefore, this study uses comprehensive techniques of PCA and fuzzy graphs to verify the reliability of the Theory of Economic, Political, and Social Distortions, the EKC, and the Pollution Haven Hypothesis in explaining the dynamic interrelations between the economy, environment, and sustainability across different income groups.

2.3 Hypothesis Development

Literature addresses challenges in achieving the SDGs in most countries, such as poverty, literacy, food insecurity, malnutrition, health disparities, and environmental issues. Over the past few decades, the majority of countries have made progress towards the SDGs by encouraging economic development and implementing redistributive measures. However, because each country's economic growth and income groups are unique, so are the trends and challenges it faces in achieving the SDGs.

Poverty has been one of the most serious issues confronting countries (Sullivan & Hickel, 2023). The worldwide poverty line is established at $2.15 per person, per day. Additionally, a multidimensional poverty measure (MPM) was introduced by the World Bank that comprised six indicators: income, access to electricity, educational aspects (achievement and enrollment), access to clean water consumption, and waste disposal (World Bank, 2023). The MPM is used to assess the poverty level of a country by considering the six indicators. However, it is difficult to create a global multidimensional measure of poverty due to the incomplete data on these indicators in certain countries. Several past researchers have analyzed the trend, impacts, and progress of the SDG and poverty indicators. Sabri & Amar (2024) suggest that poverty levels negatively impact the quality of the environment. This means countries with high poverty levels do not have concerns about environmental issues. Leal Filho et al. (2021) studied the impacts and factors that contribute to poverty using descriptive statistics. Their results showed that unemployment and climate change are major issues that contribute to and are primarily influenced by poverty. Poverty is also caused by poor economic growth, particularly in rural areas with poor environmental quality, limited access to social services and facilities, and higher rates of health and malnutrition issues. Poverty in Asian countries occurred not only between neighborhoods—urban versus rural areas—but also between ages (United Nations, 2023). Ailincă (2021) investigated the trend and progress of SDG 1 (Poverty), where the COVID-19 pandemic has caused the world's economy to significantly decline and saw a surge in unemployment in both emerging and wealthy nations, creating the worst economic crisis in 90 years. This economic downturn has had a significant negative influence on the world's progress toward the SDG target.

Moreover, during a war crisis, the rates of return to education - the difference in the prices of highly and less educated people - can increase when wages for the less educated decline due to increasing unemployment rates among the less educated, which creates a pool of unemployed, less educated people (Psacharopoulos et al., 2020). Studies (Roser & Ortiz-Ospina, 2018) emphasize that literacy is a fundamental skill and a crucial indicator of a population's education. The low-income counties have the highest significant illiterate populations due to less development in basic education, even though there has been significant advancement in basic education development and education inequalities reduction (Roser & Ortiz-Ospina, 2018). Zhao et al. (2022) stated that different income groups have different recovery plans for crises, especially during the COVID-19 crises, when children and youth were out of school and university due to lockdowns and movement restrictions, particularly in low-income groups with limited access to technology and learning facilities. From these scenarios, this study suggests poverty is the main cause of unemployment, health crises, and education in low-income groups; thus, the hypothesis is suggested as follows:

H1: Poverty is the main challenge in low-income groups for attaining SDGs.

Furthermore, wealth inequality among low- and middle-income groups has impacted the food supply chain as a result of the economy, severe food insecurity, international trade, climate change, and pandemic incidents (Irshath et al., 2023). The food system relies on the geopolitics of global food, fertilizer, finance, fodder, and fuel systems (Hendriks et al., 2022). Additionally, according to Howard (2022), the United Nations Food System Summit (UNFSS) reported that environmental climate change is making the world food supply system brittle and susceptible. Floods and droughts are prevalent issues in many Asian countries.

An increase in food unavailability causes malnourishment. According to the State of Food Security and Nutrition report, the world is reversing its efforts to eliminate hunger and malnutrition by 2030. Globally, the number of people impacted by hunger increased to 828 million in 2021, an increase of around 46 million since 2020 and 150 million since the outbreak of the COVID-19 pandemic (World Health Organization, 2022). The COVID-19 pandemic has caused disruptions in global supply chains, which have restricted access to essential supplies, materials, and fertilizers, while travel restrictions have resulted in shortages of workers, unplanted and unharvest fields, and a decline in agricultural production, thus reducing food availability (Saccone, 2021). The Global Hunger Index (GHI) Scores Report records Syria, Sudan, Somalia, Burundi, Yemen, Chad, Madagascar, Congo, and the Central African Republic as having the highest ranking with a 37–50 index in 2022 (Ali & Bhattacharjee, 2023).

These statistics show extremely alarming hunger because of a shortage of food.

Moreover, for upper-middle-income groups, some countries face poverty and undernourishment due to war and political issues. For instance, the conflict of war between Ukraine and Russia further interrupts access to the food supply chain. The underprivileged suffer from malnutrition because they consume foods that are high in energy but low in nutrition since they can obtain them at a low cost; thus, an unhealthy diet and undernutrition foods cause diseases. Poverty exacerbates malnutrition by increasing the likelihood of food insecurity (Siddiqui et al., 2020). The economic downturn and the resultant job and income losses are having an impact on income distribution, people's purchasing power, and, as a result, their economic access to food (Saccone, 2021).

This health disparity and poverty relationship has been greatly discussed in literature since 1997, and to this date, underdeveloped countries are struggling to pay for health services (Murray, 2006). As of 2019, it is reported that 55,330, 000 people are living below the poverty line as a result of paying for health care expenditures (preventive, curative, rehabilitative, long-term, or palliative care) offered by any type of health provider in any type of setting (outpatient, inpatient, or at home) for any type of illness, disease, or health condition (World Bank, 2023). World Health Statistics 2023 reports that since 2015, there has been stalled progress in access to health services due to hardships in healthcare costs, particularly for people living in less resource-rich settings (World Bank, 2023). They highlight that in 2020 and 2021, the COVID-19 pandemic resulted in 14.9 million extra deaths and a cost of 336.8 million lives lost globally, and because of immunization coverage, fewer individuals are treated for neglected tropical diseases such as malaria and tuberculosis. A study by Takian et al. (2022) reported that the COVID-19 pandemic has caused unprecedented disruptions to the delivery of and access to basic healthcare services in all contexts, particularly in low- and middle-income nations, where pre-existing health disparities and frail health systems hampered control and mitigation, thus worsening the situation.

H2: Poverty and undernourishment are the main challenges in lower and upper middle-income groups for attaining SDGs.

Environmental factors such as pollution, inadequate sanitation, radiation exposure, and other environmental causes could account for 23 percent of all deaths and thus cause social disruption and economic losses (World Health Organization, 2022). Environmental pollution, such as water, land, and air pollution, is mainly caused by industrialization and urbanization (Ukaogo et al., 2020). Fossil fuel production, industrial operations, and deforestation are the primary sources of CO_2 emissions, which produce a rise in atmospheric greenhouse gases (Begum et al., 2020; Le et al., 2024; Saraç & Yağlıkara, 2017). These actions, which are undertaken in an effort to increase economic growth, raise energy needs and consumption, and hence raise CO_2 emissions, endanger human health and sustainable development (Danish, 2020), Statistics reveal the upper middle class has the highest contribution to carbon dioxide emissions stemming from the burning of fossil fuels and the manufacture of cement, with 16, 383, 996 kilotons in 2020, followed by high-income groups with 10,864,997 kilotons, lower-middle-income groups with 4, 819,596 kilotons, and low-income groups with 179,665 kilotons (World Bank, 2023). This concludes that nations with high resource settings (high income) are the largest contributors to environmental pollution that causes climate change.

Climate change is a long-term change in current weather patterns caused primarily by humans and causing an alarming level of damage to both the environment and socioeconomic structures (World Meteorology Organization, 2023). The World Meteorology Organization (WMO) reports that three main gas houses—carbon dioxide, methane, and nitrous oxide—all set new highs in 2021 and will continue to rise further in 2022 (Dickie, 2023). The revelation of El Nino since 2020, a natural climate event that fuels tropical cyclones in the Pacific, has sparked widespread concern since it increases the likelihood of rain and flooding (Dickie, 2023). The monsoon season causes waterborne disease, food insecurity, landslides, and the loss of livestock. If all these continue, this will affect global climate change, ozone layer thinning, pollution, natural resource depletion, and ecological disruption in the long run (Saraç & Yağlıkara, 2017). The major challenge for high-income groups is to attain SDG 13, due to economic development and industrialization, which cause environmental pollution, in particular CO_2 emissions. This suggests the following hypothesis:

H3: CO_2 emission is the main challenge in high-income groups for attaining SDGs.

3. Materials and Methods

The main goal of this study is to investigate the challenges and factors: poverty (SDG 1), unemployment (SDG 8 and SDG 10), literacy among youth and adults (SDG 4), health (SDG 3 and SDG 6), food security (SDG 2), access to electricity (SDG 7 and SDG 11), and CO_2 and other greenhouse gas emissions (SDG 13) towards attaining SDGs across various income groups. These factors are selected in accordance with the SDG Summit 2023 (Fernandez, 2023) addressing the commitment of Member States to eradicate poverty, ending hunger, improving education, stronger health systems, affordable and clean energy, reducing inequalities, and combating climate

change as the most pressing and critical global challenges. The four income classes that the World Bank groups categorize the world's economies into are low, lower-middle, upper-middle, and high-income. Figure 1 shows the classification of the income groups. The list of the classifications of the income groups is displayed in Appendix A1.

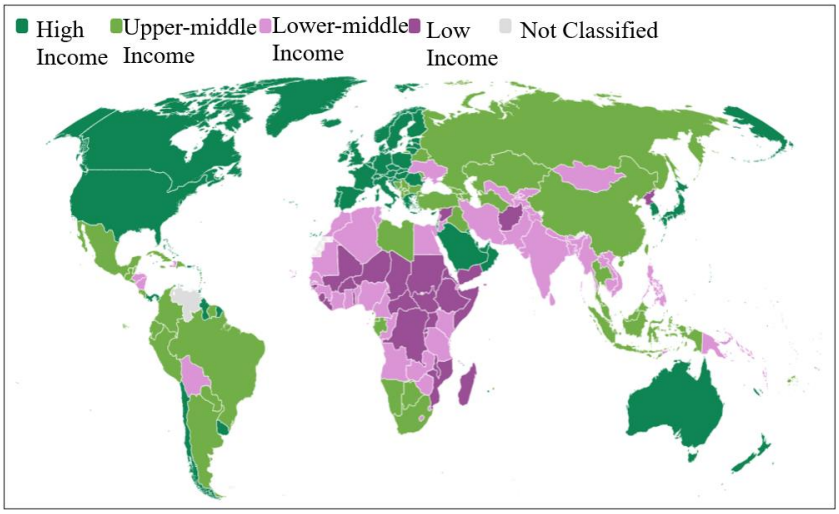

Figure 1. Classification of the income groups (Hamadeh et al., 2023)

This study makes use of panel data from the four income groups economies, involving 215 countries, for a period of 10 years from 2012 until 2021. The data were obtained from the World Bank. The variables selected in this study are depicted in Table 1 as follows: This study employs nine variables, which are poverty, unemployment, literacy among youth, literacy among adults, health (undernourishment), food security, access to electricity, CO_2 gas emissions, and other greenhouse gas emissions.

Table 1. Variables definition

Variables	Indicators	SDG Mapping	Definition
Poverty	Poverty Headcount Ratio at $2.15 a day (in percentage)	SDG 1	The population earns less than $2.15 a day (World Bank, 2023).
Unemployment	Unemployment rate (in percentage)	SDG 8 & SDG 10	The segment of the labor force that is unemployed, but actively seeking for employment (International Labour Organization, 2024).
Literacy rate among youth	Literacy rate, youth total (in percentage)	SDG 4	Individuals aged 15-24 who are capable of reading and writing everyday statements (UNESCO Institute for Statistics, 2024).
Literacy rate among adults	Literacy rate, adult total (in percentage)	SDG 4	Individuals aged 15 and above who are capable of reading and writing everyday statements (UNESCO Institute for Statistics, 2024).
Health (Undernourishment)	Prevalence of undernourishment (in percentage)	SDG 3 & SDG 6	The population whose regular food intakes are below 2.5 percent (Food & Agriculture Organization, 2024).
Food security	Prevalence of severe food insecurity in the population (in percentage)	SDG 2	At least one adult reported experiencing severe food-related struggles (skipped meals, or not eating for a full day due to financial shortage) (Irshath et al., 2023).
Access to electricity	No access to electricity (in percentage)	SDG 7 & SDG 11	Electrification data are collected from industry, national surveys and international sources (World Bank, 2023).
CO_2 gas emission	CO_2 gas emission (metrics ton per capita)	SDG 13	Carbon dioxide emissions are generated from the burning of fossil fuels, and manufacturing process during the use of solid, liquid, and gas fuels and gas flaring (Liu, 2020).
Other greenhouse gas emission	Other greenhouse gas emission (in percentage change from 1990)	SDG 13	Additional greenhouse gas emissions such as hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride (Liu, 2020).

Statistical techniques, namely Pearson correlation and PCA, are used to examine the relationship between the nine indicators and their influence on attaining the SDGs across the four income groups. Pearson correlation gives an indicator of the degree of strength of the linear connection between two variables. The closer the value of two variables to 1, the stronger the correlation between them. Cohen et al. (2009). The PCA is an established statistical method that is widely used in multivariate data analysis and summarizes a large data set into a manageable number of components for interpretation (Paul et al., 2013). The data on the first two components accounts for a significant portion of the overall variability (Paul et al., 2013). Previous research by Drastichová & Filzmoser (2019), Cling et al. (2020), and Yin et al. (2023) employed PCA in analyzing the progress and challenges of different nations in attaining the SDGs.

In this study, a fuzzy method, namely a FACS, is utilized to model the nine indicators in the form of a fuzzy graph and to further identify the dynamic and most significant indicator that influences and affects the progress of the four income groups in attaining the SDG. The FACS method was first introduced by Ahmad et al. (2010) to determine the sequence of depletion of variables and find the most significant and dominant variable through eigenvalue and Perron-Frobenius Theorem computation. Hassan et al. (2020) and Hassan et al. (2021) then introduced an advanced form of FACS and established an algorithm, namely the c-FACS, to model and analyze large and complex data. The c-FACS algorithm is generalized and modified to the FACS algorithm depicted as follows:

Algorithm 1: The FACS algorithm (Hassan et al., 2020)

1. Import variables from the dataset of a system and arrange them as input arrays.
2. Form the FACS graph, which comprises vertices from *v1* to *vn*, and the edges that connect the vertices are represented as *e1* to *en*.
3. Compute the characteristic fuzzy value of the vertices of the graph, to create fuzzy vertices.
4. Establish a matrix whereby the entries are the fuzzy values that are computed in 3.
5. Compute the eigenvectors of the matrix using the Perron Frobenius Theorem.
6. Identify the smallest eigenvector, which signifies the most insignificant component of the system.
7. Remove the corresponding nodes and link until the smallest matrix size of 2 is obtained, which signifies the most significant variable matrix.

The findings of these methods are expected to contribute to the identification of the dynamics of the factors and their significance in attaining the SDGs.

4. Results, Discussion and Implications

Table 2 describes the summary statistics of nine variables involving a 10-year period. On average, the dataset is less than 44. These datasets standard deviations are less than 30, which suggests that there is little variation within the dataset and that the data points are concentrated around the mean, which is around 44. This means the data is less spread and has higher reliability. Access to electricity and CO_2 gas emissions exhibit the highest mean, which is 43.78, whereas food security exhibits the lowest mean, which is 2.58, hence signifying the higher influence of access to electricity and CO_2 gas emissions on SDG attainment.

Table 2. Descriptive statistics

Variables	Mean	Std Deviation	Min	Max
Poverty	22.31	20.66	1	64
Unemployment	5.96	0.90	4.51	8.20
Literacy rate among youth	25.15	23.26	1	70
Literacy rate among youth	25.15	23.26	1	70
Health (Undernourishment)	33.4	26.38	1	81
Food security	2.58	3.95	1	18
Access to electricity	43.78	28.57	1	93
CO_2 gas emission	43.78	28.57	1	93
Other greenhouse gas emission	25.84	14.17	1	57

This study runs the Pearson Correlation Matrix using Stata 14. Table 3 reports the results of the Pearson Correlation Matrix to examine the relationship between two variables. The nine indicators are described as V1 (Poverty Headcount Ratio at $2.15 a day), V2 (Unemployment rate), V3 (Literacy rate, youth total), V4 (Literacy rate, adult total), V5 (Prevalence of undernourishment), V6 (Prevalence of severe food insecurity in the population), V7 (Access to electricity), V8 (CO_2 gas emission (metrics ton per capita)), and V9 (Greenhouse gas emission).

Table 3. Pearson correlation matrix

	v1	v2	v3	v4	v5	v6	v7	v8	v9
v1	1.00								
v2	-0.58	1.00							
v3	0.15	-0.05	1.00						
v4	0.14	-0.05	0.99	1.00					
v5	0.29	-0.31	0.33	0.33	1.00				
v6	-0.06	-0.17	0.32	0.35	0.17	1.00			
v7	-0.58	0.54	-0.01	0.01	0.07	0.06	1.00		
v8	-0.24	0.26	0.48	0.49	0.30	0.13	0.70	1.00	
v9	0.20	-0.09	-0.31	-0.31	0.18	-0.20	0.06	0.04	1.00

The correlation coefficient indicates the strength of the correlation, with above or below 0.6 indicating a moderate positive or negative relationship, above or below 0.8 indicating a strong positive or negative correlation, and -1 to 1 indicating a perfect linear relationship (Cohen et al., 2009). Findings show poverty is moderately and negatively correlated with unemployment and access to electricity, which indicates an increase in poverty and reduces unemployment and access to electricity. Meanwhile, the remaining variables have a low relationship with poverty. In relation to the unemployment variable, access to electricity has a moderate and positive correlation, which means an increase in unemployment will increase access to electricity. In addition, access to electricity is also positively correlated with CO_2 gas emissions (69.72 percent). For the literacy rate component, youth literacy is substantially associated with adult literacy, indicating that literacy among youth is passed over to adult literacy if not curtailed.

The data for the nine indicators from the period of 2012 to 2021 are further analyzed using PCA and FACS methods with respect to the income groups. The PCA is performed on the data for each income group using MINITAB 17 software (Minitab Inc., Pennsylvania, United States). The results are displayed in the form of a score plot, as shown in Figure 2 below.

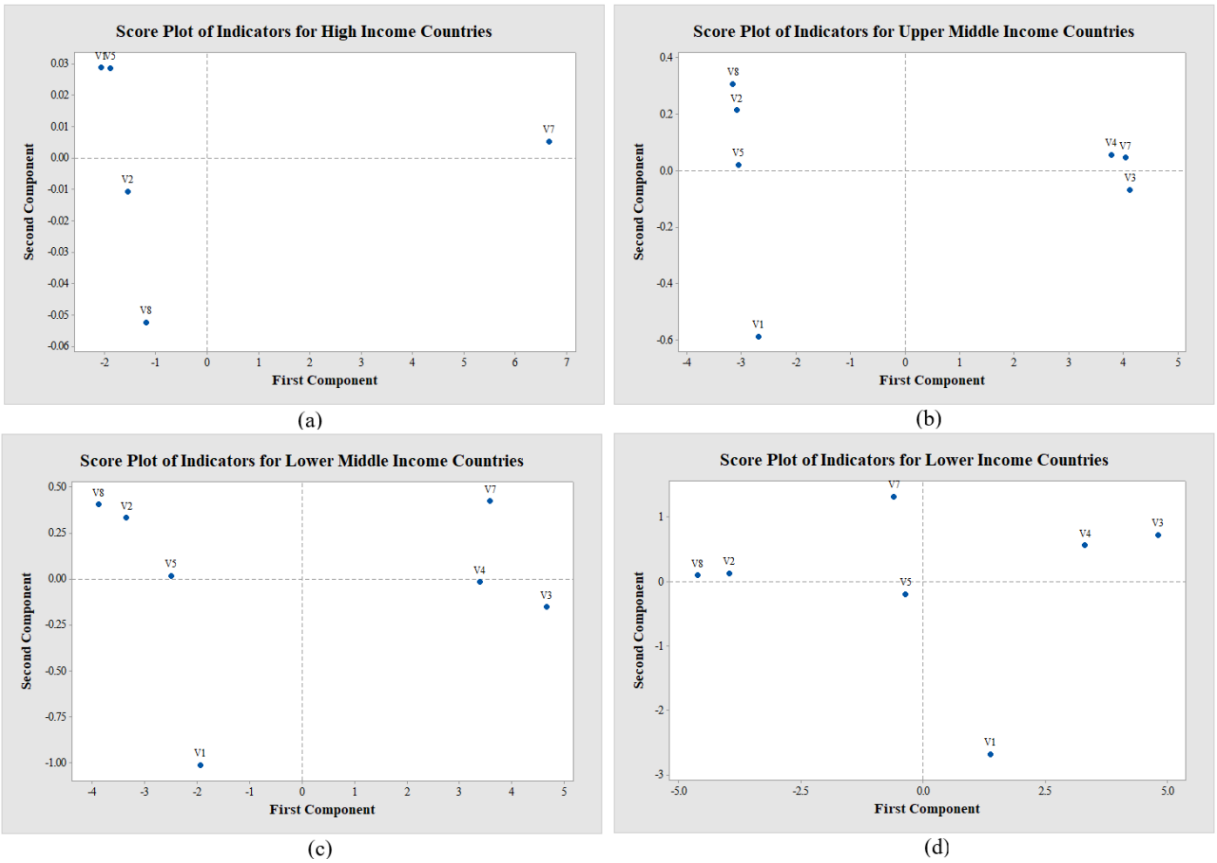

Figure 2. The PCA score plot of indicators for: (a) High-income; (b) Upper-middle income; (c) Lower-middle income; (d) Lower-income groups

The PCA score plot for high-income groups shows that V1 (Poverty Headcount Ratio at $2.15 a day) and V5 (Prevalence of Undernourishment) clustered close to each other, while the other indicators clustered further away. In particular, V8 (CO_2 gas emission (metric ton per capita)) is observed to be clustered at the negative axes of PC1 and PC2. Meanwhile, for upper-middle income, lower-middle income, and low-income groups, V1 (Poverty Headcount Ratio at $2.15 a day) and V5 (Prevalence of Undernourishment) are observed to be positioned at the negative and near-negative axes of PC1 and PC2, respectively. This is in line with the first and second hypotheses. These results indicated that poverty and undernourishment are most likely to have had less of an impact on high-income nations' progress toward achieving the SDGs since these countries have high resource sets and a low poverty rate. Whereas CO_2 gas emissions have a strong likelihood of becoming the most important component that affects the progress of high-income groups to achieve SDGs, particularly SDG 13 on climate action. The results of PCA coincide with the study of Yin et al. (2023), in which the scores in high-income groups are highly contributed to and influenced by SDG 11 (sustainable cities and communities) and SDG 13 (climate action). In addition, the results of PCA (Cling et al., 2020) reported that high-income groups are least affected by poverty and income inequality, while underdeveloped countries are influenced by poor access to health care.

Furthermore, FACS analysis is performed to further analyze the impacts and significance of the nine indicators. The FACS algorithm is performed using MATLAB software version R2017b (Mathworks, Natick, MA). Firstly, the nine indicators are modeled in a form of fuzzy graph, whereby the indicators are represented as vertices, $V = (v1, v2, v3, v4, v5, v6, v7, v8, v9)$ and the links are represented as the edges, $E = (e1, e2, e3, e4, e5, e6, e7, e8, e9)$. The data for each indicator is converted into fuzzy values ranging from 0 to 1. The fuzzy values are then constructed in the form of a matrix for further computation and identification of Perron-Frobenius eigenvectors (PFE). The lowest value of PFE and its associated set of vertices are identified and deleted through the dynamic identification of the factors. A new graph is updated with 8 vertices. The procedure for the dynamic depletion process is shown in Figure 3.

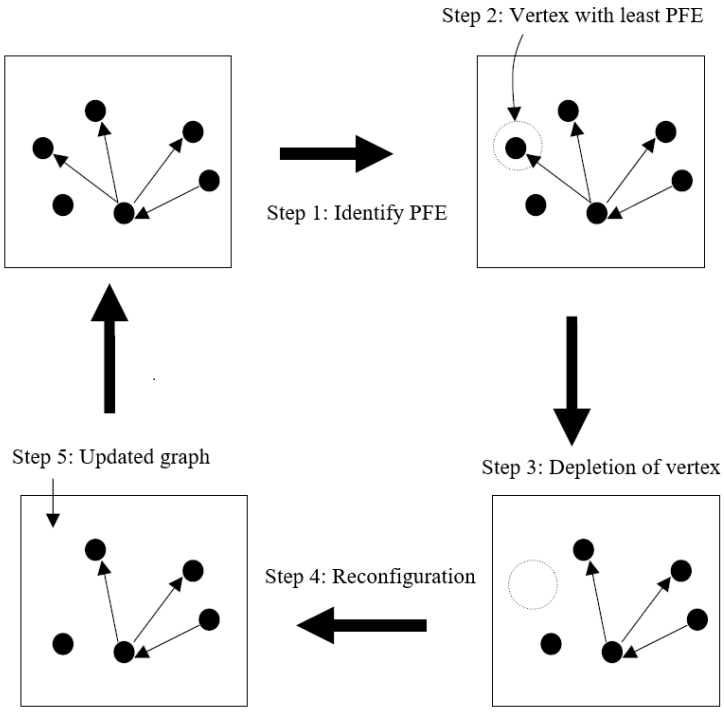

Figure 3. FACS dynamic depletion process

As a result, the FACS displays the final matrix that consists of the most dominant and significant factor (see Table 4).

The analysis is performed for each income group's country. The result for high-income groups shows that V8 (CO_2 gas emission (metric ton per capita)) is the final dominant matrix left after the FACS dynamic depletion process. The result indicates that CO_2 gas emissions are the most significant factor that has an impact on the progression of SDGs for the high-income groups, particularly for attaining SDG 13, supporting the third hypothesis. Meanwhile, the results for upper-middle income, lower-middle income, and low-income groups show a similar dominant matrix, whereby V5 (prevalence of undernourishment) is the last remaining variable after the depletion. This indicates that undernourishment is the most important factor that contributed to and impacted SDG 1 (poverty alleviation), SDG 2 (food security), SDG 3 (good health and well-being), and SDG 10 (reduced

inequality). The results of the FACS method also provide the dynamics of matrix depletion from the first matrix, second matrix, and final dominant matrix. The dynamic matrix for high-income groups shows that V5 (prevalence of undernourishment) is the first variable that is depleted from the matrix, indicating that it has the least influence on SDG attainment for high-income groups. Meanwhile, V3 (literacy rate, youth total), V7 (access to electricity), and V8 (CO_2 gas emission (metrics ton per capita)) are the least influential factors for upper-middle income, lower-middle income, and low-income groups.

Table 4. Dynamic depletion of FACS matrix for each income groups

	1st Matrix	2nd Matrix	Final Matrix
High-Income	$\begin{bmatrix} 1 & 2 & 5 \\ 7 & 8 & 0 \\ 0 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} 1 & 2 \\ 7 & 8 \end{bmatrix}$	[8]
Upper-Middle Income	$\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 7 \\ 8 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} 1 & 2 \\ 4 & 5 \end{bmatrix}$	[5]
Lower-Middle Income	$\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 7 \\ 8 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} 1 & 2 \\ 4 & 5 \end{bmatrix}$	[5]
Low-Income	$\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 7 \\ 8 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} 1 & 2 \\ 4 & 5 \end{bmatrix}$	[5]

The outcomes of PCA and FACS are aligned with each other and correspond to past research by Begum et al. (2020), Danish (2020), and Ukaogo et al. (2020) on environmental pollution and climate challenges in high-income groups. A report by the World Bank also stated that high-income groups are the largest contributors to CO_2 emissions. However, this result contradicts Wang et al. (2024), whereby high-income groups with high resource settings have a large investment in advanced technology innovation and robust infrastructure, thus the environmental quality is greater in these nations. Meanwhile, poverty and undernourishment are the most significant factors that affect and have an impact on the progress of upper-middle income, lower-middle income, and low-income groups in attaining the SDGs, particularly SDG 1 (poverty alleviation), SDG 2 (food security), SDG 3 (good health and well-being), and SDG 10 (reduced inequality). These results correlate with past research on health disparities, malnutrition, and poverty by Rehman et al. (2022), Takian et al. (2022), and a report by the World Health Organization (2022). Additionally, the result also coincides with research by Liu (2020) and Cling et al. (2020), whereby developed countries have proper health infrastructure and underdeveloped countries are least influenced by industrialization. The intersection of poverty prolongs the undernourishment that hinders socio-economic development in different income groups, encouraging holistic strategies for policymakers to tackle economic and social factors to effectively reduce social issues. The findings of this study provide implications for the government and policymakers of low, lower-middle, and upper-middle income groups to enhance social programs for welfare and food security to tackle poverty and undernourishment challenges.

Furthermore, socio-economic status and environmental factors are interconnected, as the increase in economic growth leads to high energy demand and consumption, thus impacting the environment through greenhouse gas emissions from human activities. Prior research (Dauda et al., 2021; Shah et al., 2022) addresses low-income groups continuously increasing CO_2 emissions because of trade openness; these nations are mostly manufactured for high-income groups. This means low-income groups become net exporters of carbon emissions due to the outsourcing of production by high-income nations that have stricter environmental regulations. Consequently, greenhouse gas emissions contribute to climate change, which affects socio-economic activities. Thus, it is crucial for governments to address the dynamic influence of economic activities and climate change in each income group's country for balanced economic development and environmental protection. The government and policymakers of high-income groups are encouraged to implement green energy resources and technologies to address environmental challenges. Hence, the findings of this study are crucial, particularly in balancing and enhancing the attainment of the SDGs among different income groups, for effective and tailored strategies for global sustainability.

5. Conclusions

Nine factors and impacts that influence progress in attaining SDG among four income groups are analyzed: poverty, unemployment, literacy among youth, literacy among adults, undernourishment, food security, access to electricity, CO_2 gas emissions, and greenhouse gas emissions. The data for the period of 10 years from 2012 until 2021 for each income group's country were obtained from the World Bank. A statistical technique, namely PCA, and a fuzzy technique called FACS are employed in this study to determine the most crucial and significant factors in attaining the SDGs in the four income groups.

Past research has highlighted the key factors that influence the progress of the SDGs. According to Zhao et al. (2022), SDG progress dramatically slowed down in the majority of low- and lower-middle-income groups while accelerating in high-income nations. Despite high rates of COVID-19 cases in middle- and high-income groups, progress towards the SDGs in 2020 has remained constant or, in some cases, even increased, indicating that these countries' health systems, infrastructure, markets, and regulatory systems are more resistant to crises. Meanwhile, low-income nations lack the financial flexibility to finance a sufficient healthcare response and make recovery plan investments. In most literature, health disparities, malnutrition, and poverty are cited as the main factors for low-income groups, and they are highly correlated with each other. A study by Rehman et al. (2022) stated that the main socioeconomic factors that influence issues such as health, food, and nutrition security are poverty and income inequality. Low-income and slow economic growth contribute to poverty, and low-income groups in particular are greatly affected due to pre-existing inadequate resources, thus leading to health disparities and malnourishment. A report by the World Health Organization (2022) also mentioned that millions of individuals are now affected by hunger on a global scale, especially since the outbreak of COVID-19. Additionally, the COVID-19 pandemic has exacerbated poverty, disrupted the global supply chain, limited access to resources, and severely undermined already fragile health (Takian et al., 2022).

Meanwhile, the largest factor for high-income groups is CO_2 emissions. The globalization of the economy has increased competitiveness among developed and developing countries (Danish, 2020). In order to stabilize their economies and end poverty, developing countries increase economic activity through urbanizing, industrializing, and increasing production levels. Urbanization and industrialization are the primary drivers of environmental pollution, which could cause the rise of fatalities (Ukaogo et al., 2020; World Health Organization, 2022). Due to large-scale fossil fuel production, industrialization, and deforestation, the amount of greenhouse gases in the atmosphere, especially CO_2, has reached record highs (Begum et al., 2020; Saraç & Yağlıkara, 2017). The total amount of greenhouse gas emissions rises along with population, economy, and living standards, which in turn threatens human health and sustainable development (Danish, 2020). A report by the World Bank (2023) also revealed that upper-middle groups contributed the most to carbon dioxide emissions, followed by high-income groups, lower-middle-income groups, and low-income groups.

This study extends the body of knowledge on the dynamic influence between income and environmental quality, where pollution increases when the economy grows. The results of PCA and FACS coincide with the past literature, in which the most crucial and significant challenges for attaining SDGs in high-income groups are CO_2 gas emissions. The results also coincide with the EKC and the Pollution Haven hypothesis, where environmental quality depends on economic growth and technological changes in the country, as well as disparities in the stringency of environmental regulation between developed and developing nations. This theory enhances the findings that high-income pollution occurs due to income growth (Smulders, 2004).

Additionally, the findings of this study also contribute to the extent of the of the literature on the complex interplay among socioeconomic status and geographic conditions. This study finds that poverty and undernourishment are the factors that have an impact on upper-middle income, lower-middle income, and low-income groups for achieving the SDGs. Poverty and undernourishment are in an impermeable relationship, with poverty solidifying undernourishment in low-resource settings. These findings reflect the Theory of Economic, Political, and Social Difficulties, which emphasized that when societal and economic systems are trumped, such as wage problems linked to institutional impediments, a lack of job availability for low-income people, and inadequate fringe benefits, they generate individual impoverishment regardless of competence (Quigley, 2003).

The findings of this study provide guidance to the stakeholders in government and policymakers on developing integrated policies addressing economics, social, and environmental issues of poverty and health. Expanding social welfare programs to improve the nutrition of nations as well as sustainable agricultural investment are among the holistic strategies to implement in low, lower-middle, and upper-middle income groups. Stricter environmental regulations and carbon-pricing mechanisms such as carbon taxes are useful in tackling issues of CO_2 emissions in high-income groups, which are extremely concerning given the state of the world today. High-income groups play important roles in supporting and contributing towards the economic development of lower and middle-income groups, and thus they have significant influence in strategizing socioeconomic and sustainable practices and planning.

As the scope of this study is limited to the availability of data, future research is encouraged to incorporate more factors when data becomes available to measure the current state of SDGs between nations. In addition, the fuzzy

graph method implemented in this study works better with large numbers of samples and variables; thus, the limited amount of data is not enough and may affect the performance and accuracy of the depletion of the data matrix and the dynamic identification of the factors. Therefore, further research is encouraged to develop innovative theoretical frameworks and fuzzy models that more accurately reflect the difficulties involved in accomplishing the SDGs in various geographic and economic contexts. This may entail synthesizing insight gained from environmental science, development studies, and political economy.

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Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflict of interest.

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Appendix

Appendix A1. List of the income groups (Hamadeh et al., 2023)

Income groups Economies	Gross National Income	Countries	
High-Income	$13,846 or more	American Samoa	Korea, Rep.
		Andorra	Kuwait
		Antigua And Barbuda	Latvia
		Aruba	Liechtenstein
		Australia	Lithuania
		Austria	Luxembourg
		Bahamas, The	Macao Sar, China
		Bahrain	Malta
		Barbados	Monaco
		Belgium	Nauru
		Bermuda	Netherlands
		British Virgin Islands	New Caledonia
		Brunei Darussalam	New Zealand
		Canada	Northern Mariana Islands
		Cayman Islands	Norway
		Channel Islands	Oman
		Chile	Panama
		Croatia	Poland
		Curacao	Portugal
		Cyprus	Puerto Rico
		Czechia	Qatar
		Denmark	Romania
		Estonia	San Marino
		Faroe Islands	Saudi Arabia
		Finland	Seychelles
		France	Singapore
		French Polynesia	Sint Maarten (Dutch Part)
		Germany	Slovak Republic
		Gibraltar	Slovenia
		Greece	Spain
		Greenland	St. Kitts And Nevis
		Guam	St. Martin (French Part)
		Guyana	Sweden
		Hong Kong Sar, China	Switzerland
		Hungary	Trinidad And Tobago
		Iceland	Turks And Caicos Islands
		Ireland	United Arab Emirates
		Isle Of Man	United Kingdom
		Israel	United States
		Italy	Uruguay
		Japan	Virgin Islands (U.S.)
Upper-Middle Income	$4,466 - $13,845	Albania	Kosovo
		Argentina	Libya
		Armenia	Malaysia
		Azerbaijan	Maldives
		Belarus	Marshall Islands
		Belize	Mauritius
		Bosnia And Herzegovina	Mexico
		Botswana	Moldova
		Brazil	Montenegro
		Bulgaria	Namibia
		China	North Macedonia
		Colombia	Palau
		Costa Rica	Paraguay
		Cuba	Peru
		Dominica	Russian Federation
		Dominican Republic	Serbia
		Ecuador	South Africa
		El Salvador	St. Lucia
		Equatorial Guinea	St. Vincent And The Grenadines
		Fiji	

		Gabon	Suriname
		Georgia	Thailand
		Grenada	Tonga
		Guatemala	Turkiye
		Indonesia	Turkmenistan
		Iraq	Tuvalu
		Jamaica	West Bank And Gaza
		Kazakhstan	
Lower-Middle Income	$1,136 - $4,465	Algeria	Lesotho
		Angola	Mauritania
		Bangladesh	Micronesia, Fed. Sts.
		Benin	Mongolia
		Bhutan	Morocco
		Bolivia	Myanmar
		Cabo Verde	Nepal
		Cambodia	Nicaragua
		Cameroon	Nigeria
		Comoros	Pakistan
		Congo, Rep.	Papua New Guinea
		Cote D'ivoire	Philippines
		Djibouti	Samoa
		Egypt, Arab Rep.	Sao Tome And Principe
		Eswatini	Senegal
		Ghana	Solomon Islands
		Guinea	Sri Lanka
		Haiti	Tajikistan
		Honduras	Tanzania
		India	Timor-Leste
		Iran, Islamic Rep.	Tunisia
		Jordan	Ukraine
		Kenya	Uzbekistan
		Kiribati	Vanuatu
		Kyrgyz Republic	Vietnam
		Lao Pdr	Zambia
		Lebanon	Zimbabwe
Low-Income	$1,135 or less	Afghanistan	
		Burkina Faso	Mali
		Burundi	Mozambique
		Central African Republic	Niger
		Chad	Rwanda
		Congo, Dem. Rep.	Sierra Leone
		Eritrea	Somalia
		Ethiopia	South Sudan
		Gambia, The Guinea-	Sudan
		Bissau	Syrian Arab Republic
		Korea, Dem. People's Rep.	Togo
		Liberia	Uganda
		Madagascar	Yemen, Rep.
		Malawi	