Social Indicators Research
https://doi.org/10.1007/s11205-023-03273-9

ORIGINAL RESEARCH

Multi-way Analysis of the Gender Dimension of the Sustainable Development Goals

Edith Johana Medina-Hernández[1] · **María José Fernández-Gómez**[2]

Accepted: 27 November 2023
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Abstract
The gender dimension of the Sustainable Development Goals (SDG) is integral to the goals established to foster the development of nations, as it is intertwined with other goals and enhances their attainability. Thus, this study examines 28 indicators belonging to the goals of the sustainable development objectives, distinguishing between the gender SDGs (6 indicators) and other SDGs (22 indicators), all of which were reported by 110 countries in the year 2023. The assessment considers four regions: the African continent (28 countries), the Americas region (21 countries), Asia-Oceania (29 countries), and Europe (32 countries). The STATICO multivariate technique is used (consisting of four Co-inertia analyses and one Partial Triadic Analysis) to study the interactions among the indicators. The goal is to determine whether differences or similarities exist between these indicators within each region and to make a comparative assessment across countries. The study's findings show the existing covariances between the various targets of the 2030 Agenda and indicate that in Europe, the gender dimension is more closely integrated with the other SDGs than in the other regions. In Africa, substantial variations between countries are observed, while Asia, Oceania, and the Americas face challenges in specific indicators and countries in terms of achieving sustainable development.

Keywords Sustainable development goals · Gender indicators · Multivariate analysis · STATICO

JEL Classification Q01 · J16 · K38 · C49

✉ Edith Johana Medina-Hernández
ejmedinah@ut.edu.co

María José Fernández-Gómez
mjfg@usal.es

[1] Faculty of Sciences, Universidad del Tolima, Ibagué, Colombia

[2] Statistics Department, Universidad de Salamanca (USAL), Salamanca, Spain

Published online: 27 February 2024

1 Introduction

1.1 The Sustainable Development Goals (SDGs)

As part of a political commitment to promote the development of the world's countries in several dimensions and in a manner that is sustainable over time, 193 countries subscribed the 2030 Agenda in 2015, which established 17 Sustainable Development Goals (SDGs). To monitor these goals, 169 targets and 230 indicators were defined to measure progress in various areas such as managing economic growth, providing the population decent living conditions, protecting the environment (Jain & Jain, 2020), promoting equality, encouraging innovation, fostering responsible and sustainable consumption, achieving peace, and creating conditions that favor efficient governance policies for global development (Rickels et al., 2016), among other aspects.

However, substantial structural differences exist among countries in terms of socioeconomic, political, religious, cultural, ethnic, and demographic factors. The diversity of local conditions across regions presents numerous challenges and opportunities for implementing global sustainability frameworks such as the SDGs (Moallemi et al., 2020). Despite the equal importance attributed to all goals in the 2030 Agenda (Hepp et al., 2019) and the aspirations for universality, the SDGs are not shaping up as universally applicable goals. There does not appear to be a good balance between goals for rich countries and goals for poor countries, and more domestic policy efforts are required in developing countries, particularly in poor developing countries (Gore, 2015).

The holistic and complicated nature of the goals has made their attainment difficult (Asadikia et al., 2022). Low-income countries encounter greater challenges in implementing development policies aligned with the SDGs, especially regarding targets that do not represent a major challenge for developed countries, such as the goals of ending poverty (SDG 1), managing peace and the consolidation of justice (SDG 16), providing quality education (SDG4) or facilitating access to clean water and sanitation services to the entire population (SDG 6). In contrast, developed countries, where decent employment (SDG 8) and initiatives enhancing population health and well-being (SDG 3) are more achievable, tend to prioritize goals related to climate action (SDG 13), aquatic life protection (SDG 14), terrestrial life preservation (SDG 15), responsible production and consumption (SDG 12), industrial infrastructure management and innovation (SDG 9), and clean energy (SDG 7).

Hence, accurate and effective measurement of the SDGs is imperative, considering national and regional differences, cultures and histories, and the transience of the targets proposed for each country (Lior et al., 2018). Ignoring such differences may lead to misinterpretations of the progress made by low-income countries toward achieving their targets. Aware of the differences in priorities that may exist for each country and their own national targets to 2030 to move forward in the consolidation of their sustainable development, the SDGs constitute an integrated and indivisible set of global priorities with cross-cutting targets aimed at placing people "at the center of sustainable development" by promoting conditions for equality (SDG 10). Particularly, SDG 5, focused on gender equality, emphasizes equal rights, responsibilities, and opportunities of all women and men and girls and boys and non-binary genders (Hepp et al., 2019). Under this objective, both developed and developing countries are urged to implement strategies fostering empowerment for women and girls, and to respect the equal rights of LGBTI persons.

1.2 The interdependences among the SDGs and their analysis through modeling techniques

The 2030 Agenda conceives development from a multidimensional perspective. Consequently, its targets and indicators must also be interpreted and studied multidimensionally, focusing on identifying the interdependencies between them. Since the possible associations that exist between all the SDGs can be interpreted as factors that promote or limit a country's progress. By examining the highest correlations (direct or inverse) it is possible to assess how one aspect could promote or restrict the progress of another. As noted by Pradhan et al. (2017), the SDGs can influence each other positively or negatively. Ament et al. (2020) propose that we can assess patterns of positive and negative correlations among indicators of SDGs status and progress using global UN data.

For instance, it has been found that reducing poverty is statistically linked with advancements in SDG 3 (Good health and well-being), 4 (Quality education), 5 (Gender equality), 6 (Clean water and sanitation), or 10 (Reduced inequalities). Conversely, challenges such as climate change, inequalities, and unsustainable consumption and production currently hinder the achievement of the United Nations 2030 Agenda for Sustainable Development. Several authors mention the existing interactions between the various SDGs (Ament et al., 2020; Kostetckaia et al., 2022; Pradhan et al., 2017; Sinha et al., 2020; Swain & Ranganathan, 2021; Zhu et al., 2022) to assess whether humanity can maximize synergies (positive correlations) and address trade-offs or offsets (negative correlations) that exist among SDGs. The interdependencies across different dimensions of the SDGs are frequently examined in projective and inferential studies (Güney, 2021; Nadeem et al., 2021; Weerakkody et al., 2021) or studies utilizing multivariate techniques to evaluate the performance of multiple sustainability indicators (Ferro et al., 2020; García-Sánchez et al., 2020; Martínez-Córdoba et al., 2021; Salmanzadeh-Meydani et al., 2022; Venâncio & Pinto, 2020).

1.3 SDGs and sustainability analysis by regions

In recent years, various studies have delved into the analysis of SDG indicator data to make cross-national comparisons. These studies aim to identify specific synergies among goals or to report national or regional realities reflected by the indicators. They assess the current progress level in achieving targets, estimate the timeframes required for their achievement, and outline policies and cooperation strategies necessary to attain these objectives. These analyses are particularly pertinent for the poorest countries and those undergoing developmental transitions due to the relatively new nature of sustainability science (Lior et al., 2018).

Within the African continent, studies related to SDGs (Aust et al., 2019; Bekele et al., 2019; Chitonge et al., 2020; Dube & Nhamo, 2021; Jiménez-Aceituno et al., 2020; Nhemachena et al., 2018) tend to focus on the conditions that promote fulfillment of the targets of SDGs 1, 2, 3, 5 and 10. These goals pertain to No Poverty, Zero Hunger, Good Health and Well-being, Gender Equality and Reduced Inequalities. The focus on these issues aligns with the global concern over social challenges observed within the African region (Lange et al., 2019). Additionally, investigations into sectors and institutions that promote conditions to achieve sustainable development are highly relevant in this region, particularly in low-income African countries. As highlighted by Jiménez-Aceituno et al. (2020), more studies are essential to evaluate how local interventions address SDGs and to

compare different local initiatives, hereby providing new insights into alternative pathways toward sustainability.

In the American continent, regional studies on the dimensions of the SDGs (Cho et al., 2020; Laing & Moonsammy, 2021; López-Feldman et al., 2020; Tabares, 2021) predominantly center on Latin American and Caribbean nations. In 2019, progress toward the 2030 targets was observed to be slower than anticipated in this region. Current trends suggest that due to the economic downturn caused by the COVID-19 pandemic in 2020 and 2021, the envisioned goals might not be met even within the next five decades (CODS, 2020). López-Feldman et al. (2020) emphasize that, the economic and social effects of the COVID-19 pandemic in Latin America and the measures adopted to confront it, may have serious long-term consequences on achieving SDGs in Latin America. Moreover, the COVID-19 crisis has highlighted the invisibility of gender inequalities in domestic and care work (Medina-Hernández et al., 2021).

Regarding Asia and Oceania, recent literature on the progress made towards sustainability (Herath, 2020; Huan et al., 2019; Trupp & Dolezal, 2020) underscores persistent disparities in gender equality, universal primary education, and income poverty achievements across countries (Asadullah et al., 2020). This suggests a considerable journey ahead, particularly for significant goals like eradicating income poverty in populous South Asian nations. In Europe, studies delve into the circular economy's relationship with SDGs (Rodriguez-Anton et al., 2019), the European Union's actions to preserve the environment (Duvaux-Béchon, 2019; Rickels et al., 2016; Shelestov et al., 2021), and the comparative analysis of specific SDG indicators across countries to identify key opportunities and challenges in achieving the 2030 Agenda (Bickler et al., 2020; Raszkowski & Bartniczak, 2019; Tsani et al., 2020).

In the above context, this study investigates associations between 28 SDG indicators included in the 2023 Sustainability Report (Sachs et al., 2023). The objective is to identify strengths and opportunities across 110 countries globally, categorized by regions. To emphasize the importance of the gender SDGs, the data are explored by means of the three-way multivariate analysis STATICO (Simier et al., 1999). This analysis involves two sets of data matrices: the first containing the indicators related to gender equality (SDG 5) and the second encompassing other SDGs. Thus, the main aim of this study is to evaluate the existing associations e interdependencies between gender-related SDGs and other SDGs within different world regions, providing a comparative perspective between countries. The study seeks to offer a particular view of current progress made by countries toward achieving the 2030 Agenda's targets.

2 Materials and Methods

2.1 Data in Analysis

The input data of this analysis corresponds to information from the 110 countries worldwide, selected due to the absence of missing data in 28 indicators extracted from the 2023 Sustainability Report. This report presents a quantitative assessment of the progress made by UN Member States towards achieving the Sustainable Development Goals (SDGs), offering insights into how implementing the SDGs stimulus (Sachs et al., 2023). The indicators under examination are listed in Table 1 and encompass 6 Gender SDG indicators, along with a subset of 22 additional SDG indicators related to economic aspects,

Table 1 SDG indicators in analysis

Type	SDG indicator	Code and goal
Gender	Maternal mortality rate (per 100,000 live births)	MMR.G3
	Adolescent fertility rate (births per 1,000 females aged 15 to 19)	AFR.G3
	Ratio of female-to-male labor force participation rate (%)	FML.G5
	Seats held by women in national parliament (%)	SWP.G5
	Ratio of female-to-male mean years of education received (%)	FME.G5
	Demand for family planning satisfied by modern methods (% of females aged 15 to 49)	FPS.G5
Economic	Poverty headcount ratio at $3.650/day (%)	PHR.G1
	Unemployment rate (% of total labor force)	UER.G8
	Gini coefficient adjusted for top income	GIN.G10
	Government spending on health and education (% of GDP)	SHE.G17
Health	Prevalence of stunting in children under 5 years of age (%)	PSC.G2
	Age-standardized death rate due to cardiovascular disease, cancer, diabetes, or chronic respiratory disease in adults aged 30–70 years (%)	DCD.G3
	Universal health coverage (UHC) index of service coverage (worst 0–100 best)	UHC.G3
Education	Lower secondary completion rate (%)	SCR.G4
	Literacy rate (% of population aged 15 to 24)	LIR.G4
Services	Population using at least basic drinking water services (%)	PWS.G6
	Population with access to electricity (%)	PAE.G7
	Mobile broadband subscriptions (per 100 population)	MBS.G9
	Population using the internet (%)	PUI.G9
	Satisfaction with public transport (%)	SPT.G11
Production	Production-based SO_2 emissions (kg/capita)	PSO.G12
	Electronic waste (kg/capita)	ELW.G12
	CO_2 emissions from fossil fuel combustion and cement production (tCO2/capita)	COE.G13
Biodiversity	Marine biodiversity threats embodied in imports (per million population)	MDT.G14
	Red List Index of species survival (worst 0–1 best)	RLS.G15
	Mean area that is protected in terrestrial sites important to biodiversity (%)	PTS.G15
Peace	Homicides (per 100,000 population)	HOM.G16
	Corruption Perception Index (worst 0–100 best)	CPI.G16

Source: Data of the Sustainable Development Report 2023

population health, education, services access, sustainable production, biodiversity, and peace.

The indicators in Table 1 correspond to a subset of all the indicators published in the 2023 Sustainability Report data repository.[1] They were selected for analysis in this study due to their data completeness, as other indicators were observed with a greater amount of missing data. Additionally, it must be kept in mind that the years of measurement for each indicator may vary among them, ranging from 2019 to 2023. In this regard, the selected

[1] A more detailed overview of the publication for each indicator can be found on the website: https://dashboards.sdgindex.org/

variables may be susceptible to outliers associated with different stages of the economic cycles of the countries.

The country-level data (refer to Table 2) is analyzed based on regions: 28 nations from the African continent, 21 countries from the Americas region (including Latin America, the United States and Canada), 29 countries from Asia-Oceania and 32 European countries. For graphical representation in the study results, the countries are represented using the ISO 3166 ALPHA-3 abbreviations.

Given that the study's scope is exploratory, descriptive, and correlational, no predefined hypotheses have been formulated concerning potential interdependence relationships. To examine the relationship between gender indicators and other SDG across regions, the data are structured as a sequence of four pairs of matrices. Each pair corresponds to a geographic region (continent) with their countries in the rows. The columns are the gender SDGs and the other SDGs, respectively. This arrangement results in two three-way datasets: one for the gender SDGs and one for the rest of the SDGs. The first way is the countries, the second the indicators, and the third the regions. This data configuration can be effectively analyzed using the STATICO multivariate technique.

2.2 The STATICO Analysis Technique (STATIS and Co-inertia)

STATICO was proposed by Simier et al. (1999) and later developed by Thioulouse et al. (2004), as an exploratory method for the analysis of the relationships between the structures of two series of K data tables. This technique is comprised by the application of two methods: Co-inertia, proposed by Dolédec and Chessel (1994) and Triadic Partial Analysis proposed by Jaffrenou (1978), that was initially called Triadic Analysis by Thioulouse et al. (2004) and later was named Partial Triadic Analysis (PTA) by Kroonenberg (1989) and X-STATIS by Abdi et al. (2012).

In STATICO, which is considered a multi-block method, the aim is to find a stable typology among the K-matrices (K = 4 continents), by analyzing the existing relationship among the two sets of K-tables X_k and Y_k (Gender SDG indicators and other SDGs), through the K-cross matrices, according to the procedure described in Fig. 1.

STATICO entails the following sequential steps: Each pair of matrices in each k-condition (region) is jointly analyzed using the Co-inertia technique, with the intention of finding the directions (axis) on both matrices with maximum covariance. So, a succession of crossed tables (gender SDG indicators × other SDG indicators) is obtained. Previously, each table of the pair is individually analyzed by means of a Principal Component Analysis (PCA) (Hotelling, 1933, 1936; Pearson, 1901) when all the variables are numeric, as is the case in this study. Lastly, a PTA (or X-STATIS) is applied to analyze this series of crossed tables, in order to investigate if the covariation structures are stable in the different regions. In summary, the STATICO is a X-STATIS of a series of cross-covariance tables obtained by crossing the variables of each pair of data tables.

The process to analyses the data with the STATICO technique, is summarized in Fig. 1.

2.3 Information preprocessing: Data matrices conformation

The data, sourced from the 2023 Sustainability Report, was organized by identifying countries with complete information (no missing values) across the indicators of interest. This dataset undergoes analysis subsequent to centering and scaling the indicators. This approach is employed to mitigate possible biases in interpretation that could arise due to

Table 2 Countries in analysis

	ISO3	Country	ISO3	Country	ISO3	Country
Africa	AGO	Angola	GMB	Gambia	SLE	Sierra Leone
	BDI	Burundi	KEN	Kenya	TCD	Chad
	BWA	Botswana	MAR	Morocco	TUN	Tunisia
	CAF	Central African Republic	MOZ	Mozambique	TZA	Tanzania
	CMR	Cameroon	MRT	Mauritania	UGA	Uganda
	DZA	Algeria	MWI	Malawi	ZAF	South Africa
	EGY	Egypt, Arab Rep	NAM	Namibia	ZMB	Zambia
	ETH	Ethiopia	NER	Niger	ZWE	Zimbabwe
	GHA	Ghana	NGA	Nigeria		
	GIN	Guinea	RWA	Rwanda		
Americas	ARG	Argentina	DOM	Dominican Republic	PAN	Panama
	BOL	Bolivia	ECU	Ecuador	PER	Peru
	BRA	Brazil	GTM	Guatemala	PRY	Paraguay
	CAN	Canada	HND	Honduras	SLV	El Salvador
	CHL	Chile	JAM	Jamaica	URY	Uruguay
	COL	Colombia	MEX	Mexico	USA	United States
	CRI	Costa Rica	NIC	Nicaragua	VEN	Venezuela, RB
Asia and Oceania	ARE	United Arab Emirates	IRN	Iran, Islamic Rep	NPL	Nepal
	ARM	Armenia	IRQ	Iraq	PAK	Pakistan
	AUS	Australia	ISR	Israel	PHL	Philippines
	AZE	Azerbaijan	JOR	Jordan	RUS	Russian Federation
	BGD	Bangladesh	JPN	Japan	SYR	Syrian Arab Republic
	BTN	Bhutan	KAZ	Kazakhstan	THA	Thailand
	CHN	China	KOR	Korea, Rep	TUR	Türkiye
	GEO	Georgia	LKA	Sri Lanka	VNM	Vietnam
	IDN	Indonesia	MNG	Mongolia	YEM	Yemen, Rep
	IND	India	MYS	Malaysia		
Europe	ALB	Albania	FRA	France	MLT	Malta
	AUT	Austria	GBR	United Kingdom	NLD	Netherlands
	BEL	Belgium	GRC	Greece	NOR	Norway
	BLR	Belarus	HRV	Croatia	POL	Poland
	CHE	Switzerland	HUN	Hungary	PRT	Portugal
	CZE	Czechia	IRL	Ireland	ROU	Romania
	DEU	Germany	ITA	Italy	SRB	Serbia
	DNK	Denmark	LTU	Lithuania	SVK	Slovak Republic
	ESP	Spain	LVA	Latvia	SVN	Slovenia
	EST	Estonia	MDA	Moldova	SWE	Sweden
	FIN	Finland	MKD	North Macedonia		

Source: Author's elaboration based on data in the Sustainable Development Report 2023

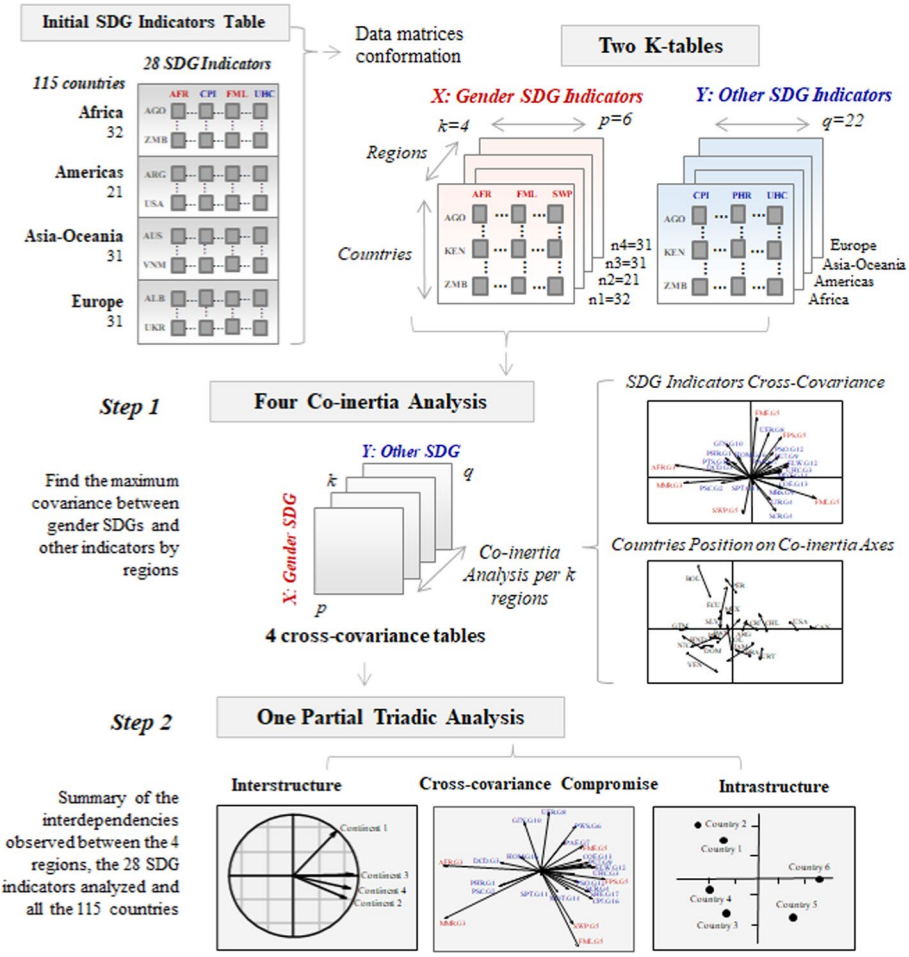


Fig. 1 STATICO Method Analysis Process

variations in the scales or ranges of individual variables. The information is structured into two data cubes (X_k and Y_k in Fig. 1), where the columns reflect the types of indicators explored (SDGs related to gender and other SDGs), the rows summarize nations, and the third dimension denotes the respective regions. The steps of the analytical procedure using the Co-inertia and X-STATIS techniques are described below.

2.3.1 Step 1: k Co-Inertia Analysis

The aim of this technique is to find the common structure (co-structure) between the pairs of the multivariate $\mathbf{X}_k$ and $\mathbf{Y}_k$ data matrices, which have at least one characteristic in common. In this study, the same observations are laid out in rows (countries), for each continent (k condition), and there are different variables in the matrices of each cube (p = 6 Gender SDG indicators and the remaining q = 22 SDGs). Initially, each matrix is analyzed independently by means of PCA, obtaining the cross-sectional matrix of the weights of the

observations in the hyperspace of principal components R^p and R^q with metric $\mathbf{D}_p$ and $\mathbf{D}_q$ respectively, which identify the main axes that represent the direction of the vectors that maximize the projected variability (inertia).

Next, the eigenvalues analysis of each cross-matrix: $\mathbf{X}_k{}^T\mathbf{D}_{n,k}\mathbf{Y}_k\mathbf{D}_q\ \mathbf{Y}_k{}^T\mathbf{D}_{n,k}\mathbf{X}_k\mathbf{D}_p$, is performed, where $\mathbf{X}_k{}^T$ and $\mathbf{Y}_k{}^T$ are the transpositions of the original matrices $\mathbf{X}_k$ and $\mathbf{Y}_k$ respectively, $\mathbf{D}_{n,k}$ is the matrix with the weights for the rows (countries), and n represent the number of rows (countries) in each matrix, for k = 1,…,4.

Through this procedure, we obtain the cross-covariances table between the variables of two data tables, and the covariance between the projections of the rows (countries) of each matrix of the pair on its corresponding Co-inertia axis is maximized. The level of association between the matrices (XY Co-inertia) is interpreted as high when the two structures vary simultaneously, either directly or inversely; otherwise, the structures are considered to vary independently or not to vary.

Graphically, the results of the co-inertia for each k condition (regions) can be interpreted over the representation of the cross-covariance between the studied p (gender SDGs) and q (other SDGs) variables, which are usually represented in the form of vectors on a plane. Additionally, the observations (countries) of each matrix are jointly represented in a graphic of co-structure, using an arrow to connect the same pair of countries. When these arrows are long, it means that the co-structure is low, if they are short, the co-structure is high.

2.3.2 Step 2: The Partial Triadic Analysis

To simultaneously analyze the information from the K-cross-covariance tables obtained in step 1, the STATICO method uses the Partial Triadic Analysis (or X-STATIS), which is a three-way data analysis method based on the concepts of vector variance and vector covariance (Escoufier, 1973), and which computes the coefficients between data tables. This technique requires that each matrix contain the same variables (p columns) and the same number of individuals (n rows). Let K be the number of tables analyzed ($\mathbf{X}_k$), ($\mathbf{X}_k$,$\mathbf{D}_p$,$\mathbf{D}_n$) defines a statistical triplet, where $\mathbf{D}_p$ and $\mathbf{D}_n$ are positive definite weighting matrices for variables and observations and whose positive diagonal elements sum to 1.

This method consists of 3 substeps: the Interstructure analysis, which analyzes and calculates the importance of each matrix in the analysis to build a compromise matrix; 2 construction and analysis of this compromise, which captures the standard structure among the matrices; and 3 the analysis of the Intrastructure through the projection of the rows (countries) on the compromise space.

Thus, in the first procedure involved in this technique, called the Interstructure analysis, as exemplified by Mendes et al. (2010), a matrix of scalar products between tables is computed (i.e., the matrix whose elements are: $\mathrm{COVV}\left(\mathbf{X}_k, \mathbf{X}_l\right) = \mathrm{tr}(\mathbf{X}_k^T\mathbf{D}_n\mathbf{X}_l\mathbf{D}_p)$). The diagonalization of this matrix provides eigenvectors. The k coefficients α_k of the first eigenvectors are then used to weight the k tables in the calculation of the compromise table. Alternatively, with the intention to rescale the importance of the tables, it is possible to compute a matrix of vector correlations (RV) (Robert & Escoufier, 1976).

Each element in this table is: $\mathbf{RV}(\mathbf{X}_k, \mathbf{X}_l) = \frac{\mathrm{COVV}(\mathbf{X}_k,\mathbf{X}_l)}{\sqrt{\mathrm{VAV}(\mathbf{X}_k)}\sqrt{\mathrm{VAV}(\mathbf{X}_l)}}$; so that $0 \le (\mathbf{X}_k, \mathbf{X}_l) \le 1$, where $\mathrm{COVV}(\mathbf{X}_k, \mathbf{X}_l)$ represents the vector covariance between the matrices, and $\mathrm{VAV}(\mathbf{X}_k)$ and $\mathrm{VAV}(\mathbf{X}_l)$ are the vector variances. $\mathrm{VAV}(\mathbf{X}_k)$ is obtained by putting all the columns of table $\mathbf{X}_k$ one below the other. It is basically the vector variance of table $\mathbf{X}_k$, i.e., $\mathrm{VAV}\left(\mathbf{X}_k\right) = \mathrm{tr}(\mathbf{X}_k^T\mathbf{D}_n\mathbf{X}_k\mathbf{D}_p)$).

The coefficient RV takes values between 0 and 1 and reveals, with a high value, a greater relationship between the covariation structures of the variables of both matrices analyzed. This RV coefficient is known as the vector correlation coefficient and is a multivariate extension of the Pearson correlation coefficient, with the fundamental difference that it measures the existing correlation between data tables instead of between variables.

This RV-matrix is analyzed by means of a PCA. This analysis provides a graphic representation in which each condition is represented by a vector. Additionally, the Interstructure analysis provides a weigh for each table, obtained from the first eigenvector of the analysis, in order to make a weighted average of each table called the Compromise. The PCA analysis of this compromise provides a graphic representation of the average covariation structure between the two set of variables and allows defining a scenario for the representation of the trajectories of the observations (countries).

Thus, the compromise enables the analysis of the average interdependencies that exist between the studied gender indicators and the other SDG indicators. The last stage of the analysis is the Intrastructure, which enables examining the trajectories of the observations (countries) of each data table through the third way of interest (continents), and their relative position by projecting the rows of the original matrices onto the compromise space.

This technique has been popular for the study of ecological and environmental information (Mendes et al., 2012; Slimani et al., 2017; Thioulouse et al., 2018), and has recently been used in the context of socioeconomic analysis (Gallego-Álvarez et al., 2015; Rodríguez-Rosa et al., 2019; Santos et al., 2017). The statistical package R (open access) has the ade4 and adegraphics functionalities (Chessel et al., 2004; Dray & Dufour, 2007; Dray et al., 2003; Siberchicot et al., 2017; Thioulouse et al., 2018) that enable performing this methodology.

3 Results

The study's results are presented below, beginning with an exposition of some descriptive patterns and the bivariate correlations obtained for all the studied indicators. Subsequently, the results obtained with the multivariate STATICO technique are disclosed. In alignment with the methodological framework of this technique, the multidimensional analysis results are divided into two stages. The initial stage entails the description of the four Co-inertia analyses (one for each continent or region). This is followed by the presentation of the findings from the Partial Triadic Analysis, which summarizes the existing interrelationships between all the studied SDG indicators.

3.1 Descriptive Results

To illustrate the behavior of the SDG targets, Fig. 2 displays a comparison between regions and countries in terms of the progress made at 2023 for the following indicators: Percentage of the population that receives at least 3.65 US dollars per day to live on (PHR), ratio of female-to-male labor force participation rate (% FML), ratio of female-to-male mean years of education received (% FME) and those who have access to clean water (PWS).

In Fig. 2, it can be seen that there is greater variability in Africa which indicates that this region further public efforts are required to achieve the SDGs. In contrast, in Europe, all the countries report low poverty levels, drinking water is available to almost 100% of the population and achievement of the FME target is reported at close to 100%, which

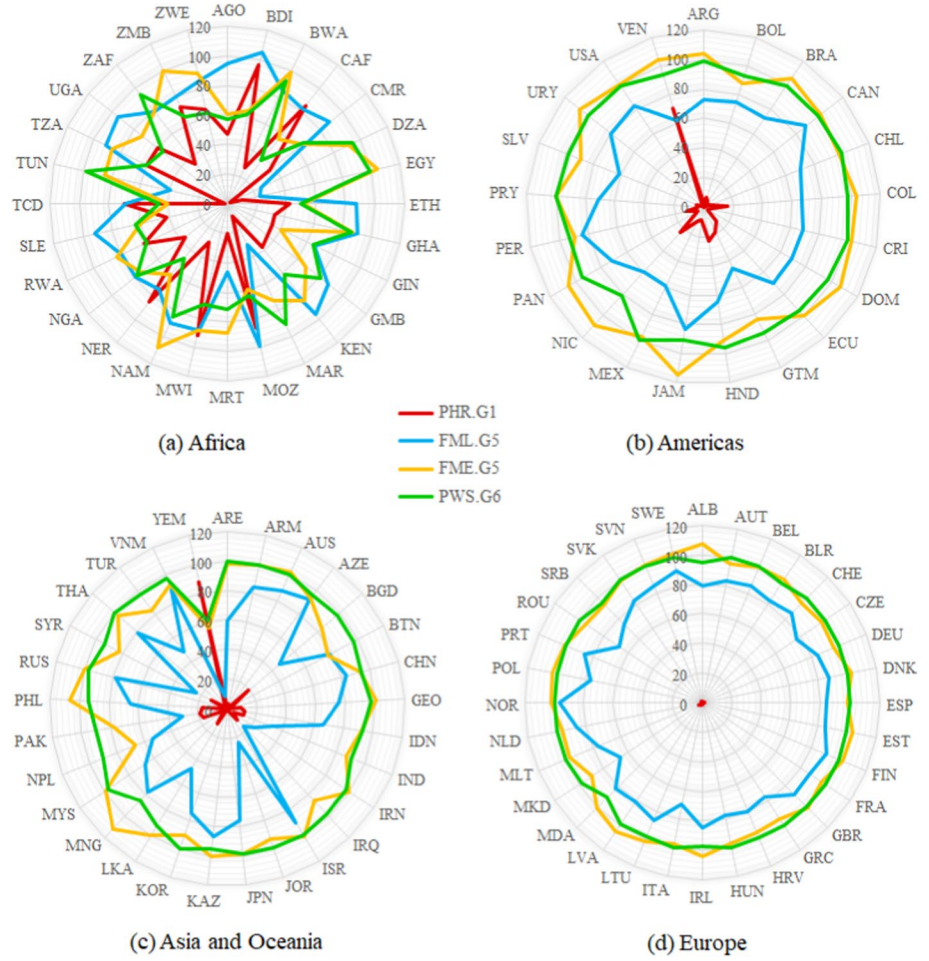


Fig. 2 Comparison by regions and countries of SDG indicators: PHR, FML, FME and PWS

implies that there are less differences between men and women in terms of access to formal education. Specifically in the countries of the Americas (Fig. 2(b)), Venezuela (VEN) displays an atypical result in terms of the poverty indicator (PHR), given that 70.06% of its population receives 3.65 USD or less for their subsistence. Honduras (HND) is the second most precarious country in terms of poverty.

Among the Asian countries (Fig. 2c), Yemen reports a more critical percentage than Venezuela, with the 87.26% of their population below this poverty threshold. Regarding the behavior of the FML indicator, it should be noted that in some countries the participation of women in labor markets is critical, because for every 100 men who work there are less than 30 women who do so. In Africa (Fig. 2(a)), this situation is observed in Egypt (EGY: 22.2%) and Algeria (DZA: 25.6%). In the countries of Asia and Oceania (Fig. 2(c)), Yemen and Iraq report the least favorable conditions for women in the labor market (YEM: 8.8% and IRQ: 16.4%), followed by the Islamic Republic of Iran (IRN: 22.6%), Jordan (JOR: 23.5%) and Syria (SYR: 23.3%).

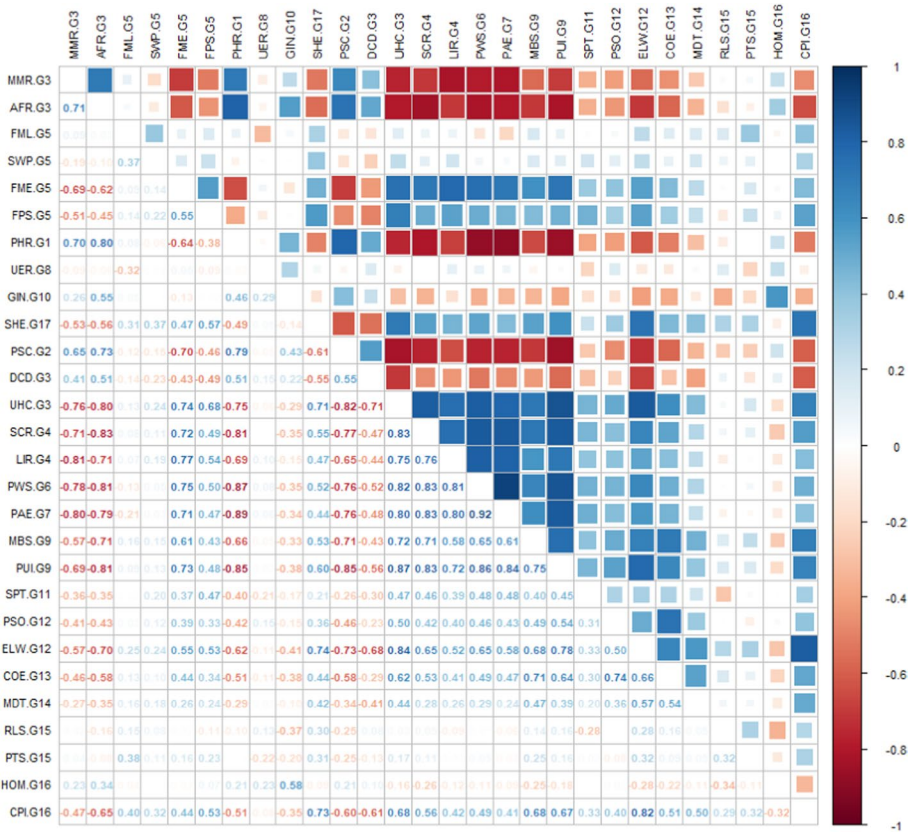


Fig. 3 Bivariate correlations between SDG indicators

The Fig. 3 displays the graph of bivariate correlations between pairs of variables, calculated using the Pearson's coefficient with data from all 110 nations under analysis. Positive correlations are displayed in blue, and negative (inverse) correlations are displayed in red. The intensity of the color reflects the strength or weakness of the correlation, in which the lightest shades represent a coefficient that approaches zero. Figure 3 shows that the indicators with weakest associations are FML (Ratio of female-to-male labor force participation rate, which belongs to goal 5), SPT (Satisfaction with public transport, under goal 11), and RLS and PTS (Red List Index of species survival and Mean area that is protected in terrestrial sites important to biodiversity, under goal 15).

In contrast highly correlated pairs are observed, for example of PAE with PWS (correlation of 0.92), which reflects that when a high percentage of a country's population has access to electricity, a high percentage of the population also has at least basic drinking water services. This association is consistent in that both are basic household utility services. One of the highest inverse correlations in Fig. 3 is that between MMR and LIR (correlation of − 0.81), which implies that the lower the literacy rate in the population between the ages of 15 to 24 in a country, the higher the percentage of maternal mortality.

Table 3 Co-inertia axes and correlations between axes in the cross-covariance analysis

Continent	Co-inertia Axis	Projected inertia	Eigenvalues
Africa	Axis1	87.92%	20.6791
	Axis2	9.51%	2.2366
Americas	Axis1	84.91%	16.4061
	Axis2	7.09%	1.3704
Asia-Oceania	Axis1	91.07%	23.3679
	Axis2	3.94%	1.0116
Europe	Axis1	79.67%	13.944
	Axis2	9.41%	1.6478

Source: Author's calculations in R based on data in the Sustainable Development Report 2023

3.2 Results through the STATICO technique

3.2.1 Step 1: Four Co-Inertia Analyses

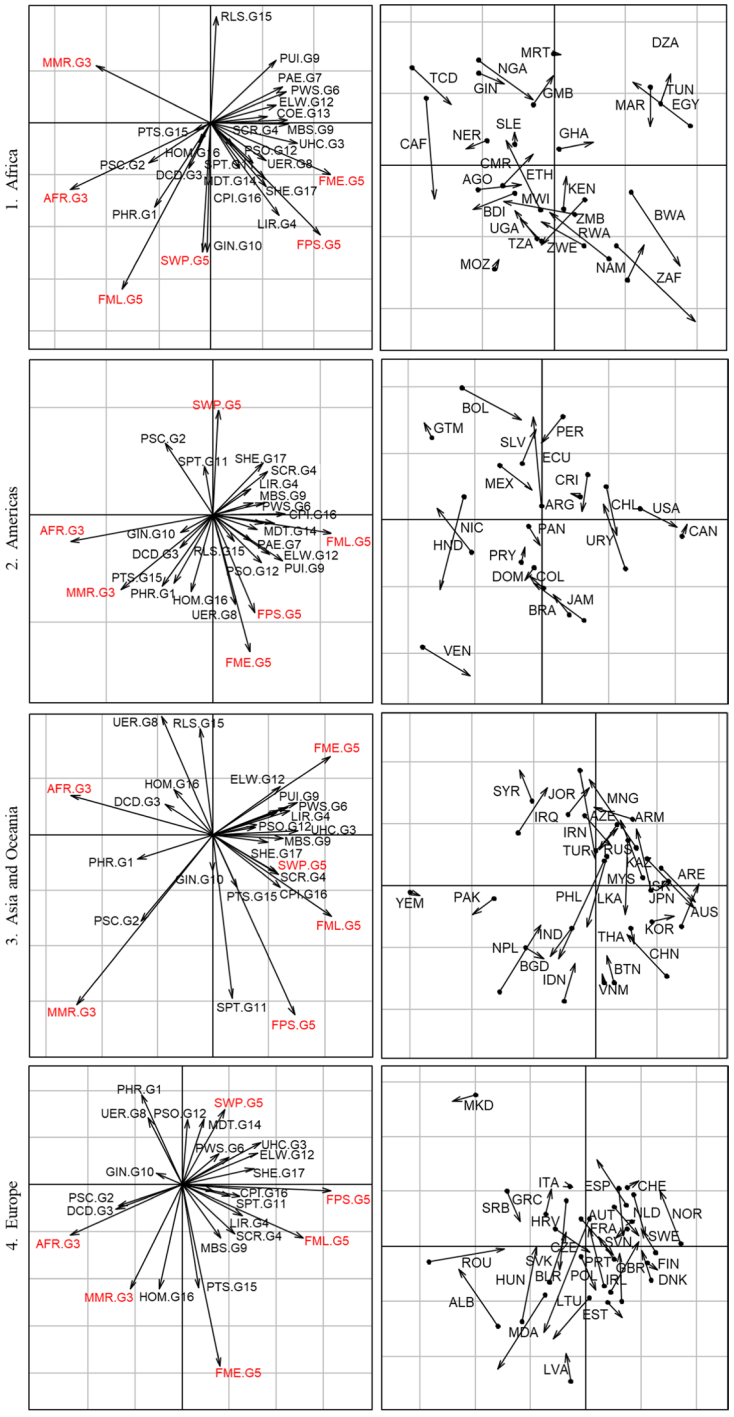
Before graphically interpreting the results of the multidimensional analysis, it is relevant to discuss the projected inertia from running separately the 4 Co-inertia analyses between the gender SDGs and the other, when analyzing the tables of indicators by regions, as well as to explain the observed correlations between the Co-inertia axes that result from the process of reducing the number of dimensions by means of PCA. These results are shown in Table 3. They indicate that the accumulated inertia of the first two axes, in the four regions, is greater than 89%, so it would not be necessary to study more than two axes.

The Fig. 4 displays the graphic results of the Co-inertia analysis by continents displaying the covariation structures between the gender SDG indicators and the other indicators (Fig. 4a) and the graphs of co-structure reflect the projections the standardized coordinates of the countries onto the co-inertia axes of the two data sets (Fig. 4b).

Starting by describing what is observed in Africa, Fig. 4a shows that the indicators with greatest variability (i.e., the longest vectors on the plane) are three gender indicators: MMR, AFR and FML (towards the left on the plane) and RLS, which runs in the direction of Axis 2. This behavior reflects a significant variability of this indicator among countries, suggesting that some African countries must continue working to reduce maternal mortality and the adolescent fertility rate and promote greater access to the labor market for African women, aiming to provide similar conditions compared to men. Improvements must also be made on the Red List Index of species survival (RLS), which is observed with one of the most extensive lengths in the plane in the direction of axis 2.

In Fig. 4b, where each country's position is its projection onto the co-inertia axes of the set of gender SDG indicators and the co-inertia axes of the other SDGs, it can be seen that countries such as Chad, Central African Republic and Nigeria currently report high rates of maternal mortality per 100,000 live births (TDC: 1,063, CAF: 835 and NGA: 1,047). The countries that report the best RLS indicators include Mauritania and Gambia (MRT and GMB), as they are located in the direction of axis 2 in the plane.

The Fig. 4b also displays common characteristics between Tunisia (TUN), Morocco (MAR), Algeria (DZA) and Egypt (EGY), which are determined by a set of vectors that run very close to each other, located in the direction of quadrant I of the plane, running in the direction from axis 1. In these countries, high percentages of the population have



(a) SDG Indicators Cross-Covariance (b) Countries Position on Co-inertia Axes

Fig. 4 Co-structure graphs of the Co-Inertia Analysis by regions

access to electricity and basic water service (PAE and PWS), and they also have the best percentages in Africa in terms of the internet use (PUI) and the population have had completing secondary education (SCR).

The performance of South Africa (ZAF) also stands out from among the other countries in quadrant IV of the plane, in the direction of the vectors that represent the indicators: demand for family planning satisfied by modern methods (FPS), literacy rate (LIR), women's participation in formal education (FME) and the percentage of GDP invested in education and health (SHE).

As for the countries of the American continent, displayed in Fig. 4a, it is also possible to observe that the gender indicators AFR and MMR are close to each other, in the opposite direction from axis 1, which implies that countries with high adolescent fertility also have high prevalence of maternal mortality, and vice-versa. Based on the location of the countries on the plane in Fig. 4b, Guatemala, Nicaragua, Honduras, and Venezuela (GTM, NIC, HND and VEN) face the most critical situation in the continent in connection with these two indicators that belong to SDG 3.

In Fig. 4b, in the opposite direction from the Central American countries and Venezuela, we find Canada and the United States in the direction of axis 1, with the best sustainable development indicators of the continent and high scores in indicators such as CPI, MDT, and UHC, which indicate that the population does not believe that government institutions are corrupt (CPI), efforts are made to protect endangered species and marine biodiversity (MDT) and to provide healthcare services to their citizens (UHC).

Regarding the Co-inertia results for the countries of Asia and Oceania, the graph in Fig. 4a shows high covariance between the gender indicators related to women's participation in the labor market, access to modern family planning methods and participation in national parliaments, given that FML, FPS and SWP, located in quadrant IV of the plane. The association between these gender indicators was not as pronounced in the African and American countries. Based on the location of the countries of Asia and Oceania on the plane of Fig. 4b, it can be seen that Australia, South Korea and China (AUS, KOR and CHN) are the countries that have made most progress in achieving the SDGs that seek gender equality. On the contrary, the countries that face greatest challenges in the region in terms of controlling maternal mortality and adolescent fertility, represented by MMR and AFR, which run towards the left of the graph, are Yemen, Pakistan, Nepal, Bangladesh, Iraq, and India (YEM, PAK, NPL, BDG, IRQ, and IND).

In these nations, there is also a need to reduce indicators such as deaths in adults from cardiovascular diseases, cancer, or diabetes (DCD, from SDG3), stunted growth in children under five years of age (PSC from SDG 2), and percentage of the population subsists below the poverty line of 3.65 USD per day (PHR from SDG 1). The proximity to axes 2 of Syrian Arab Republic, Jordan, Iran, Iraq and Turkey, (SYR, JOR, IRN, IRAQ and TUR), in the direction of the UER indicator, reflects the higher unemployment rates in these countries than in the other countries of the continent. Instead, the close proximity to axis 1 of Australia, Japan, Israel, and United Arab Emirates (AUS, JPN, ARE and ISR) reflects their high contribution to sustainable development in the region.

Concerning the European countries, Fig. 4a represents the covariances among the SDG indicators and the nations relative positions. Similar to observations made for the countries in the American continent, the gender indicator with lowest covariance compared to other gender SDG targets is SWP, which represents seats held by women in the countries' parliaments. By examining the relative positioning of countries, those situated further down of the plane, in addition to have under the female political leadership, reports indicators above the European average in the SDGs as: homicides rate (HOM), adolescent pregnancies

Table 4 Percentage of inertia explained in the PTA analysis

	Axis1	Axis2	Axis3	Axis4	Axis5
Eigenvalues	53.2205	1.3754	1.1933	0.7129	0.3643
Projected inertia (%)	93.3939	2.4137	2.094	1.251	0.6393
Cumulative projected inertia (%)	93.39	95.81	97.9	99.15	99.79

Source: Author's calculations in R on ade4 library (Chessel et al., 2004)

(AFR), maternal mortality, deaths caused by cardiovascular disease, cancer, diabetes, or chronic respiratory disease in adults aged 30–70 years (indicators MMR and DCD) and stunted growth in children under 5 years old (PSC).

The Fig. 4b shows a conglomerate of countries that are very close to each other, in the direction of axis 1, including Norway, Sweden, Netherlands, Finland, Denmark, Belgium, France, United Kingdom and Germany (NOR, SWE, NLD, FIN, DNK, FRA, GBR and DEU). These countries report the best sustainable development indicators in Europe. In Fig. 4d it can be seen that the set of indicators that characterizes these countries includes UHC, ELW, SHE, CPI, SPT, FPS and FML which co-vary mutually with each other and also run in the direction of axis 1.

The results obtained from these four co-inertia analyses allow us to speak of the existence of a particular underlying covariation structure between the indicators of the two sets of SDGs, which is not easy to establish through visual inspection of the previous graphs. Thus, in the second step of STATICO, a PTA of the cross-tables cube is carried out to bring to light the common structure and to be able to compare the positions of the countries with each other concerning said average structure or commitment.

3.2.2 Step 2: One Partial Triadic Analysis (X-STATIS)

In the Partial Triadic Analysis, the percentage of variance explained by the first eigenvector of the RV coefficient matrix is important because it allows us to evaluate the quality of the compromise to represent the best consensus of the single cross-covariance matrices (refer to Table 4). These values correspond to the percentage of inertia explained by each of the eigenvectors resulting from diagonalizing the RV matrix.

As the compromise is a weighted average of the cross-covariance matrices with weights represented by the first eigenvector of the RV coefficient matrix, rescaled to unit sum; it is also important to report the weight of each k table: Africa (0.211), Americas(0.262), Asia-Oceania (0.277), and Europe (0.25).

With the intention of summarizing the existing associations between the 6 gender indicators and the other 22 SDG indicators that were assessed, Fig. 5 presents the cross-covariance compromise and the intrastructure of the PTA analysis. In relation with the Compromise (Fig. 5a), it can be seen that the gender indicators are distributed over the plane, co-varying with each other and with the other SDG indicators. It can also be seen that three of the longest vectors are those that represent the indicators female labor market participation, adolescent fertility, and maternal mortality (FML, MMR and AFR). The fact that these vectors are longer implies that they are the SDG indicators with greatest variability, which can be interpreted as indicating that substantial differences still remain between the countries of the world in these 3 aspects.

The compromise in Fig. 5a shows that the countries with high values in the AFR and MMR indexes also demonstrate a tendency towards elevated values in DCD and PHR, i.e., adolescent fertility and maternal mortality are associated with the poverty threshold and tend to have high prevalence of death from diseases such as cancer, diabetes, or chronic respiratory disease in adults aged 30–70 years. This interrelation is further accentuated by their covariance with HOM, the indicator for homicides per 100,000 inhabitants. All these conditions limit the sustainable development of the world's nations.

On the other hand, the vectors located in quadrants I and IV of the plane are associated with conditions that seek to favor sustainable development. Specifically, regarding the gender targets of the 2013 Agenda, these vector quadrants represent conditions that promote access to education and the egalitarian participation of men and women in the labor market (indicators FME and FML) and promote access to family planning methods (FPS).

All these indicators covary positively with indicators such as SCR, UHC, CPI, PUI, or SHE, which represents the secondary completion rate, the universal health coverage, the positive perception of the population regarding low levels of corruption in their governments, the total subscriptions to broadband internet service, and the public spending on health and education. However, at the same time, they maintain a positive and direct relationship with indicators that represent compensation for the search for sustainability in the world, such as ELW and MDT, which refer to waste electrical and electronic equipment and threats to marine species incorporated in imports of goods and services. Aspects in which the nations (especially the developed ones) still have pending challenges because they need to continue improving the preservation of the environment.

Regarding the indicators that do not refer to the gender dimension of the SDGs, the indicators with greatest variability in the plane are found near axis 2 and they represent the unemployment rate and the area that is protected in terrestrial sites important to biodiversity (UER and PTS). Instead, a large set of indicators with lower variability and with high covariance with each other are found in the direction of axis 1, which in summary can be considered to represent sustainable development.

To conclude the interpretation of the results, Figs. 5b, c presents the intrastructure of the PTA, in which each of the 110 studied countries is projected onto the compromise. Therefore, Fig. 5b summarizes the relative position of the countries from the gender SDG perspective, and Fig. 5c presents the position of the countries from the other studied SDG indicators point of view. Despite the differences in the countries' positions in Figs. 5b, c, by interpreting their locations compared to the structure of vectors in the compromise space of Fig. 5a it can be seen that those located in the right part of axis 1 are the ones with the world's highest sustainable development. In contrast, those located in the opposite direction face greater opportunities and challenges to advance on the 2030 Agenda.

For example, in terms of the gender indicators, Canada (CAN), Norway (NOR) and Egypt (EGY) are the leaders in terms of the search for equality between men and women, whereas Chad (TCD) has the world's highest rate of maternal mortality (1,063 women who die giving birth for each 100,000 live births) and Albania (ALB) has the lowest FPS indicator (6.3% of females aged 15 to 49 who have access to modern family planning methods).

Fig. 5 Compromise and Intrastructure in the PTA ▸

4 Discussion

4.1 Findings Related to the Covariation Among SDGs Indicators

This study's results indicate a high level of co-variation between the different SDG targets, which can be interpreted as synergistic factors propelling countries towards sustainable development. Conversely, when observing negative associations, they provide actionable insights to surmount barriers hindering the attainment of SDG objectives. The descriptive analysis undertaken in this study, specifically the calculated bivariate correlations indicate that 57% of them were positive. This result is consistent with the findings of Horvath et al. (2022), Medina-Hernandez et al. (2023), and Pradhan et al. (2017). The last authors for example, systematize the identification of synergies and trade-offs using official SDG indicators, finding that for a given SDG, positive correlations between indicator pairs were found to outweigh the negative ones in most countries.

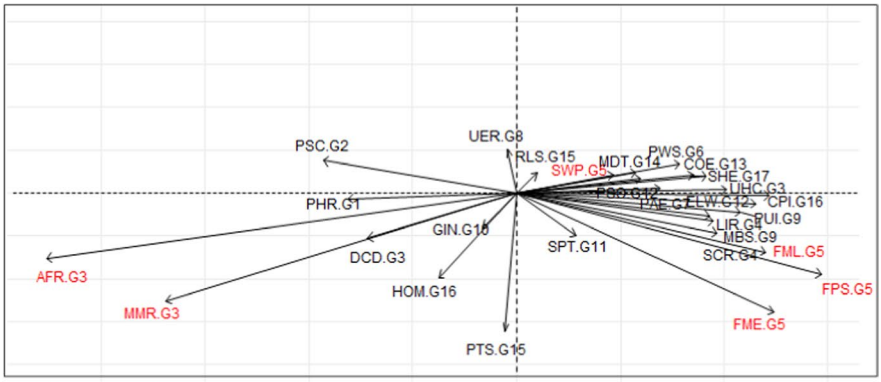
The cross-covariance compromise of the STATICO analysis indicates an association between maternal mortality and poverty, measured at the threshold of 3.65 USD per day. Moreover, maternal mortality is correlated with the prevalence of stunted growth in children under the age of 5. These three aspects require improvement within the framework of the Agenda 2030, particularly in low-income countries. As suggested by Lange et al. (2019), less developed countries might have difficulties achieving the SDGs because of their low level of socioeconomic development.

4.2 Findings Related to Regions and Countries

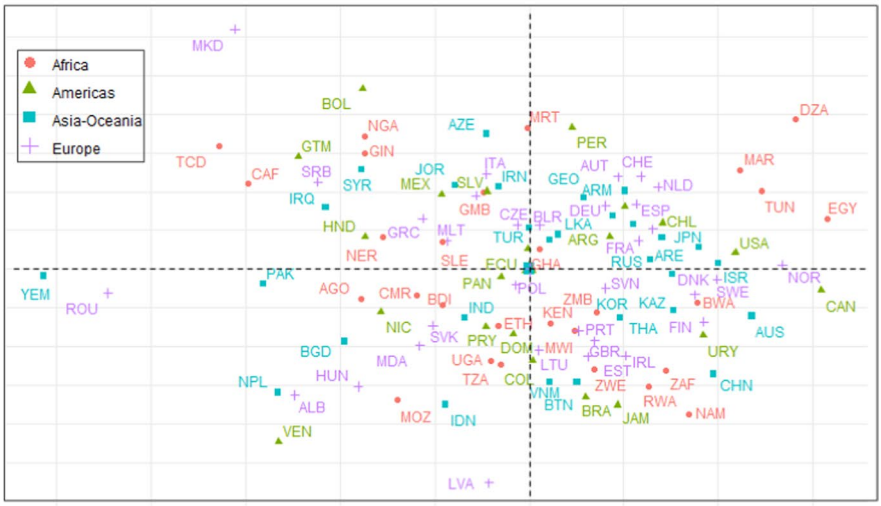
When considering findings by regions and continents, three important aspects emerge: the high variability observed across regions, the differences and similarities between regions found in terms of the gender dimension of the SDGs, and the other studied SDG indicators. The descriptive analysis performed by continents shows greater variability in the values of the SDG indicators reported by African countries compared to other regions. This heightened variability may reflect the greater challenges Africa faces in improving the quality of life for its population. As noted by Izugbara et al. (2021), this continent requires strategies to generate transformations in women's political and economic participation, as well as declines in child malnutrition, gender-based violence, police brutality, corruption, and environmental degradation.

Instead, the European countries, and particularly European Union members, exhibit lower variability in current progress towards the SDGs. Furthermore, the Interstructure analysis within the PTA indicates that gender dimensions in European countries are more closely integrated with other SDG indicators compared to other regions. This finding is important in that it suggests that strategies implemented by Europeans have been more effective in empowering women and girls, promoting equality for non-binary genders, and recognizing gender equality as a crucial condition for sustainable development.

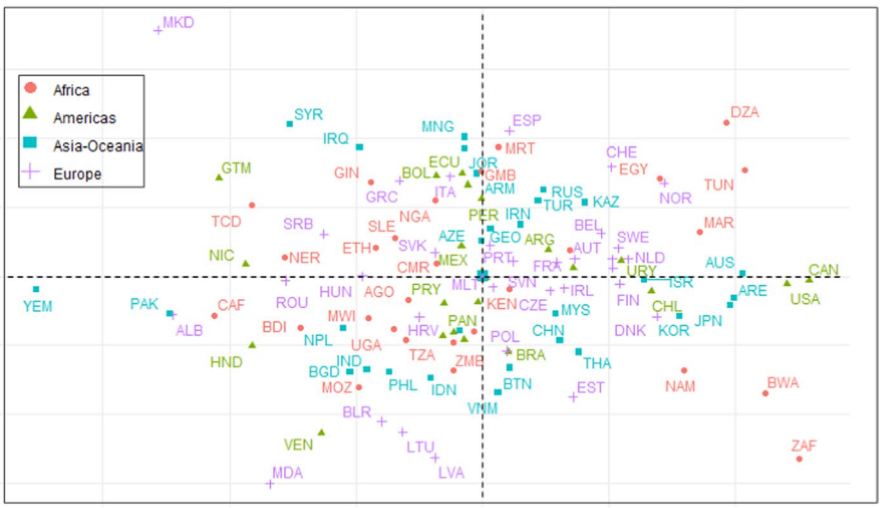
In this study, major differences were found between regions and countries worldwide, emphasizing the need for strategies on three fronts: ***i***. Create inclusive workplaces with equal conditions for men and women. Countries like Jordan, Algeria, Egypt, Iraq, Iran, Pakistan, Bangladesh, India, and Venezuela currently face precarious conditions in this



(a) Cross-covariance compromise



(b) Projections of the countries onto the compromise space from the gender SDG indicators



(c) Projections of the countries onto the compromise space from the other SDG indicators

aspect. ***ii.*** Mitigation of risks related to maternal mortality and promotion of sexual and reproductive health among girls and adolescents, enabling them to decide when to become mothers. Chad, Central African Republic, Sierra Leone, Guatemala, Nicaragua, Honduras, Venezuela, Bulgaria, Moldova, Ukraine, Hungary, and Romania encounter significant challenges in these areas. ***iii***. Continuation of efforts to enhance women's political participation at the parliamentary level.

In this last item, among the countries studied, only Rwanda, South Africa, Bolivia, Costa Rica, Mexico, Nicaragua, United Arab Emirates, Finland, and Sweden have over 45% of parliamentary seats held by females. Thus, it is pertinent to cite Freidenberg et al. (2018) to draw conclusions about this observed trend. We believe that the international regulations and political-electoral reforms designed to ensure the presence of women in positions of political representation will not, in themselves, ensure gender equality and that they must be complemented by other policies in the economic, cultural, and educational areas to help overcome the various forms of sexism and violence (physical and symbolic) faced by women in politics.

Concerning the set of studied SDG indicators not directly related to gender equality, Co-inertia analyses conducted by region show that some countries stand out for having high scores in different targets of the 2030 Agenda. Notably, in Africa, Tunisia, Morocco, Algeria, Egypt and South Africa; in the Americas, Canada and the United States; in Asia and Oceania, Australia, China, Japan, Israel and United Arab Emirates; and in Europe, Norway, Sweden, Netherlands, Finland, Denmark, Belgium, France, United Kingdom and Germany. The most of these countries are classified as "high-income" economies by the World Bank (2022).

These findings affirm the argument put forth by Aust et al. (2019), greater progress has been observed in industrialized countries, although many developing countries have also realized the need to seek sustainability. It is also worth reflecting on what is indicated by Dentinho et al. (2021), different regions imply different rankings of the UN goals. However, some of these disparities are denials of the problems of their surroundings. Researchers from dependent countries deny the need for institutional changes. Scientists from poor countries do not prioritize better nutrition and sustainable agriculture. Regional scientists from emerging countries do not consider gender equality a top issue. Finally, scholars from rich countries seem to think that aims come easily without better cities and more growth.

4.3 Technical Observations

One aim of this study was to illustrate the utility of multivariate techniques for the analysis of the SDGs. The STATICO, the Co-inertia analysis and the PTA are three alternatives that can be used in future research with a gender focus that seeks to assess the existing interactions between the sustainability indicators. As highlighted by Khalikova et al. (2021), we found increasing attention to gender in other areas of sustainability research (climate change, corporate social responsibility, food production, resource management, energy policy, and environmental behavior and education). These techniques, along with other multidimensional methods and unsupervised learning approaches, can be understood as useful methodologies for visualizing data that are highly multidimensional. Because these are tools for the use of statistical algorithms that help summarize and group large amounts of data (Moallemi et al., 2020).

Finally, it's important to acknowledge a limitation of this study: the evaluated SDG indicators may not yet encompass the full impact of the COVID-19 pandemic

on impeding progress toward the 2030 Agenda. It is therefore important to consider that as COVID-19 has battered the world and its economies, it might be time to rethink the path toward the sustainability of our planet, by reconsidering new ways of achieving the SDGs in the post-pandemic era (Zhao et al., 2022). Nonetheless, it is unlikely that enough money or attention will be allocated to eliminating poverty and inequality, expanding medical care, and reversing the loss of biodiversity and climate change, all by 2030 (Naidoo & Fisher, 2020).

5 Conclusion

The analyses showed the usefulness of the multivariate STATICO technique in investigating the interaction between the gender SDG indicators and the rest of the SDG indicators. This elucidates the aspects that either underpin or hinder equality among women and girls, as well as the conditions that facilitate or hinder sustainable development. Concerning the association and interdependence between gender-related SDGs and the other goals of the 2030 agenda, it is possible to conclude that exist heterogeneity between regions and within the nations of each continent.

In Europe, the gender dimension is more integrated into the other SDG objectives compared to the remaining continents. In Africa, the association of maternal mortality, adolescent fertility, and the unsatisfied demand for family planning methods stands out, with a poverty threshold of USD 3.65 per day for subsistence. In Asia and Oceania, the indicator for years of education received between women and men covaries positively with universal health coverage and the percentage of the population that uses the Internet. Among the countries of the Americas, specifically in Canada and the United States, the satisfied demand for planning methods directly covaries with indicators such as universal health coverage and the population's confidence in low government corruption.

As a consequence of the above, the analyzes carried out contribute to the recognition of gender research as an integral facet of sustainability, cutting across diverse objectives of the 2030 Agenda. This dimension aids in identifying the opportunities for promoting equality between women and men in different countries while aiming to strike a balance between the productive systems of the different economies of the world and the sociodemographic needs of the population. Hence, the outcomes of this study underscore the ongoing necessity to pursue the empowerment of women and girls in society, as an essential condition to promote nations' development and sustainably consolidate their future.

Data and code availability The information analyzed in this article corresponds to data available on the web site: https://dashboards.sdgindex.org/. The code will be provided upon request.

Declarations

Conflict of interest There are no conflicts of interest to report.

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