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Mapping the Sustainable Development Goals Relationships

Luis Miguel Fonseca [1,*], José Pedro Domingues [2] and Alina Mihaela Dima [3]

[1] Centre for Research & Development in Mechanical Engineering (CIDEM), School of Engineering of Porto (ISEP), Polytechnic of Porto, 4249-015 Porto, Portugal

[2] Production and Systems Department & ALGORITMI Centre, Minho University, Minho University, 4710-057 Braga, Portugal; pdomingues@dps.uminho.pt

[3] Department of Business Administration in foreign languages (UNESCO Chair), Faculty of Business Administration in foreign languages, Bucharest Academy of Economic Studies, 010374, Bucharest, Romania; alina.dima@ase.ro

* Correspondence: lmf@isep.ipp.pt; Tel.: +351-228-340-500

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Abstract: Sustainable development addresses humanity's aspiration for a better life while observing the limitations imposed by nature. In 2015, the United Nations General Assembly approved the 17 Sustainable Development Goals (SDGs) with the aim to foster the organizational operationalization and integration of sustainability and, therefore, to address the current and forthcoming stakeholder needs and ensure a better and sustainable future for all, balancing the economic, social, and environmental development. However, it is not entirely clear which are the mutual relationships among the 17 SDGs and this study aims to tackle this research gap. The results of the correlation confirm that Poverty elimination (SDG1) and Good health and well-being (SDG3) have synergetic relationships with most of the other goals. SDG7 (Affordable and clean energy) has significant relationships with other SDGs (e.g., SDG1 (No poverty), SDG2 (Zero hunger), SDG3 (Good health and well-being), SDG8 (Decent work and economic growth), SDG13 (Climate action)). However, there is a moderate negative correlation with SDG12 (Responsible consumption and production), which emphasizes the need to improve energy efficiency, increase the share of clean and renewable energies and improve sustainable consumption patterns worldwide. There is also confirmation that SDG12 (Responsible consumption and production) is the goal strongly associated with trade-offs. To sum up, this research suggests that change towards achieving the Sustainable Development Goals offers many opportunities for reinforcing rather than inhibiting itself. However, some SDGs show no significant correlation with other SDGs (e.g., SDG13 (Climate action) and SDG17 (Partnerships for the goals), which highlights the need for future research.

Keywords: sustainable development; sustainable development goals; relationships; synergies; trade-offs; correlation

1. Introduction

Sustainable Development (SD) was first defined as "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs," in the document "Our Common Future" by the United Nations Commission on Environment and Development (Brundtland Commission). SD aims to address humanity's aspirations of a better life within the limitations imposed by nature [1].

Subsequently, in 1997, the United Nations Agenda for Development building on the Brundtland SD definition and the Elkington [2] triple bottom line approach (people, planet, profit) approach, stated that: "Development is a multidimensional undertaking to achieve a higher quality of life for

all people. Economic development, social development, and environmental protection are interdependent and mutually reinforcing components of sustainable development" [3]. Each of these factors has played a major role in recent years in terms of efforts for innovation, financing and global development. In terms of social development, besides the eradication of poverty and well-being of the population, quality education is another significant factor nowadays, that is bringing also innovation in ways of teaching, especially in terms of digital teaching, but also increased mobility of pupils and students, notably since the integration in the European Union and the Bologna process started [4]. In the economic field entrepreneurial entries, innovation, knowledge economy development and digitalization, such as the introduction of robotic automation processes for the business have become some of the main variables for enhancing competitiveness and further market and business development [5,6]. Another main focus point today is the environmental protection and sustainable development in the form of renewable energy, such as wind, solar and other forms of green energy, for which also a sustainable development has to be ensured through diverse support policies, community project inclusion and financing programs [7]. Moreover, research has shown that, at country level, there is high correlation (and a possible relationship) between social sustainability, innovation and competitiveness [8].

In 2015, the General Assembly of the United Nations (UN) formally adopted ''The 2030 Agenda for Sustainable Development," which provides a framework for ''peace and prosperity for people and the planet, now and into the future" [9]. As part of this agreement, all United Nations Member States, after a participated process involving multiple stakeholders, agreed upon the Sustainable Development Goals (SDGs), which can be used to provide an indication and measure of progress towards the main objective of sustainable development [10]. The SDGs represent a shared expression of stakeholder needs at a global level balancing economic, social, and environmental development [11]. The 17 SDGs, presented in Table 1, comprehend themes such as ending world poverty to undertaking urgent action to combat climate change and its impacts by 2030, and are outlined in the UN's document "Transforming our World: The 2030 Agenda for Sustainable Development" [9] and in the United Nations sustainable development goals platform [12]:

Table 1. Sustainable Development Goals (UN-SDGs, 2019).

Sustainable Development Goals (SDGs)	Description
SDG 01. No poverty	• End poverty in all its forms, everywhere
SDG 02. Zero hunger	• End hunger, achieve food security and improved nutrition, and promote sustainable agriculture
SDG 03. Good health and well-being	• Ensure healthy lives and promote well-being for all at all ages
SDG 04. Quality education	• Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
SDG 05. Gender equality	• Achieve gender equality and empower all women and girls
SDG 06. Clean water and sanitation	• Ensure available and sustainable management of water and sanitation for all
SDG 07. Affordable and clean energy	• Ensure access to affordable, reliable, sustainable and modern energy for all
SDG 08. Decent work and economic growth	• Promote sustained, inclusive and sustainable economic growth, full and productive employment, and decent work for all
SDG 09. Industry, innovation, and infrastructure	• Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation
SDG 10. Reduced inequalities	• Reduce inequality within and among countries
SDG 11. Sustainable cities and communities	• Make cities and human settlements inclusive, safe, resilient and sustainable

SDG 12. Responsible consumption and production	• Ensure sustainable consumption and production patterns
SDG 13. Climate action	• Take urgent action to combat climate change and its impacts
SDG 14. Life below water	• Conserve and sustainably use the oceans, seas and marine resources for sustainable development
SDG 15. Life on land	• Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation, and halt biodiversity loss
SDG 16. Peace, justice and strong institutions	• Promote peaceful and inclusive societies for sustainable development, provide access to justice for all, and build effective, accountable and inclusive institutions at all levels
SDG 17. Partnerships for the goals	• Strengthen the means of implementation and revitalize the global partnership for sustainable development

The SDGs aim to inspire the operationalization and integration of Sustainability into organizations worldwide, addressing current and future stakeholder needs, and contributing to the achievement of sustainable development for society at large. However, although this global initiative is an authoritative source of inspiration, the different interpretation of the SDGs calls for further efforts by policymaking to improve the understanding and scientific resonance of future SDG-like initiatives, and there are still open issues regarding SDG performance measurements, operationalization, and interlinkages [13]. Assessment of the 17 SDGs has considerably focused on formulating appropriate targets and indicators for each goal [14]. Moreover, as outlined by Sachs [15] (p. 2206), the SDGs ''aim for a combination of economic development, environmental sustainability, and social inclusion", and thus, by definition, must embrace a wide range of targets and indicators. The interlinkages and integrated nature of the SDGs are critical to attaining sustainable development [16]. It is, therefore, relevant to research the possible relationships (trade-offs and complementarities) in achieving the various SDGs. After the introduction, a literature review of the SDGs relationships and the Sustainable Development Goal Index (SDG-I) is presented, followed by the methodology section. The paper ends with the results presentation and the discussion of the relevant findings and its implications and limitations.

2. Literature Review

2.1. The SDGs Relationships

The SDGs assume a significant role in the present sustainability and policy discussions concerning development as acknowledged by Scherera et al. [17]. It is recognized that there is some progress towards the SDGs. However, some critics, such as Des Gasper [18], argue that there are missing themes in the SDGs, such as migration, terrorism, capital flight, and democracy. However, rather than a judgment based on a conceptual and technical dimension, it should be acknowledged that collectively, according to Biggeri et al. [19], they represent a roadmap for a better future that inspires action and cooperation among diverse multilevel actors and agents of change with the freedom to adjust to different contexts and purposes.

Table 2, presented below, summarizes recent research contributions assessing potential relationships between SDGs. The results suggest that the understanding of the relationships between the SDGs remains limited [20]. Correlations between SDGs mainly point towards synergies, but also indicate trade-offs [21]. There are situations where the achievement of an SDG makes impossible the progress on another or where the success in an SDG is contingent on the success of another [22]. For example, since poverty and inequality are reflected in consumption volumes [23], the developments on poverty alleviation (SDG1) and reduction in inequalities (SDG10) might lead to increased environmental impact. This is due to the fact that most of the environmental effects can be attributed both directly and indirectly (via the supply chains) to the consumption by households [24]. It is, therefore, critical to understand which are the relationships between SDGs and their extent, and to

realize (or not) that a specific achievement may impact positively or negatively on other SDGs and their targets [19].

Table 2. Observed relationships between SDGs.

Author	Findings
Barbier and Burgess, 2017 [14]	• Reducing poverty (SDG1) can be further boosted by positive gains from improvements in Clean Water and Sanitation (SDG6) and Zero Hunger (SDG2). Reducing poverty (SDG1) and hunger (SDG2) as well as improving access to Clean water and sanitation (SDG6) between 2000 and 2015 may have come at the expense of other environmental and social SDGs, making our economies less sustainable.
Fuso-Nerini et al., 2017 [25]	• Identifies 113 targets that require action to enhance energy systems and evidence of a link between 143 targets and "access to affordable, reliable, sustainable and modern energy" (SDG7). Trade-offs relate to tension between the need for rapid action to address key issues for human well-being (for example, poverty eradication, access to clean water, food and modern energy, and so on), and the careful planning needed to achieve efficient energy systems with a high integration of renewable energy.'
Pradhan et al., 2017 [21]	• Poverty elimination (SDG1) has a synergetic relationship with most of the other goals; and health and well-being (SDG3) has synergies with other SDGs in most countries and across most population groups. SDG12 (Responsible consumption and production) is the goal most associated with trade-offs.
ICSU, 2017 [26]	• Presents a detailed analysis of target level interactions for four SDGs and finds evidence of 50 positive interactions for SDG2 (Zero hunger), 81 positive interactions for SDG3 (Good health and well-being), 46 positive interactions for SDG7 (Affordable and clean energy) and 61 positive interactions for SDG14 (Life below water). The analysis identifies a set of potential constraints and conditionalities among targets in SDG2, SDG3, SDG7 and SDG14 that require coordinated policy interventions to protect the vulnerable, ensure equity and manage competing demands over natural resources to support sustainable development.
Singh et al., 2018 [27]	• Focuses on how SDG14 (Life below water) contributes to other goals eliminating poverty (SDG1) and ending hunger (SDG2) are highly dependent on ocean sustainability. Protecting marine areas can exclude access to coastal resources and restrict progress towards ending hunger (SDG2) and curbing disparities that affect poor people (SDG10).
UN, 2019, [28]	• Meta study found the most significant relationships, in terms of synergies, between: - SDG 02 (Zero hunger) and SDG 01 (No poverty) and SDG 03 (Good health and well-being). - SDG 03 (Good health and well-being) and SDG 08 (Decent work and economic growth). - SDG 06 (Clean water and sanitation) and SDG 12 (Responsible consumption and production). - SDG 07 (Affordable and clean energy) and SDG1 (No poverty), SDG2 (Zero hunger), SDG3 (Good health and well-being), SDG8 (Decent work and economic growth), SDG13 (Climate action). - SDG8 (Decent work and economic growth) and SDG1 (no poverty). - SDG 11 (Sustainable cities and communities) and SDG 03 (Good health and well-being). - SDG 12 (Responsible consumption and production) and SD6 (Clean water and sanitation). - SDG13 (Climate action) and SDG15 (Life on land). - SD14 (Life below water) and SDG1 (No poverty), SDG2 (Zero hunger) and SDG8 (Decent work and economic growth). - SDG15 (Life on land) and SDG1 (No poverty), SDG2 (Zero hunger), SDG8 (Decent work and economic growth), SDG13 (Climate action) and SDG14 (Life below water). Concerning trade-offs, the most significant relationships, were found between: - SDG2 (Zero hunger) and SDG6 (Clean water and sanitation) and SDG15 (Life on land). - SDG7 (Affordable and clean energy) and SDG6 (Clean water and sanitation) - SDG13 (Climate action) and SDG14 (Life below water).

The above research emphasizes the interlinked and integrated nature of the SDGs, which highlights the need to identify possible synergies and trade-offs to attend the different SDGs and make progress on all 17 goals to ensure sustainability, as posited by the UN [16] and authors such as Sachs [15] and Barbier and Burgess [10,14].

The literature review indicates that although progress across all 17 SGGs is possible, improvement toward one SDG may either reinforce or harm progress towards another goal. For example, economic expansion and industrial growth contributed to poverty or hunger reduction and the elimination of hunger, while improving access to clean water and sanitation, and ensuring good health and well-being. However, this economic and industrial development also had negative impacts on some environmental or social goals [14,21,25,26,28]. Such reported trade-offs and synergies amongst SDGs are in line with the United Nations' report on progress in attaining the various 2030 SDG targets [16]. The UN report emphasizes the declines, since 2000, of extreme poverty, infant and maternal mortality rates, while the access to electricity has improved worldwide. However, the ''material per capita footprint" of developing countries has grown up, and the sustainably of fish, and forest area stocks have declined. Other investigations also stressed the potential interactions among attaining different SDGs, e.g., with SDG 07 (Affordable and clean energy) [25,28].

Some studies aim to investigate the synergies and trade-offs between all the 17 SDGs, while others focus on some of the 17 SDGs or the 169 other goals and are not comparable between themselves. In a nutshell, SDG 01 (No poverty) and SDG 07 (Affordable and clean energy) show the most relationships with other SDGs, whereas SDG12 (Responsible consumption and production) is the goal mostly associated with trade-offs.

2.2. The Sustainable Development Goal Index

The Sustainable Development Goal Index (SDG-I), has been developed by Jeffrey Sachs et al. [29] on behalf of Bertelsmann Stiftung and the Sustainable Development Solutions Network (SDSN). It aims to develop and apply a single unified indicator for monitoring progress towards the SDGs at the global level and support the identification of priority areas for action, follow the overall development, and allow for international comparisons and benchmarking.

The SDG-I relies on available data from several publicly accessible sources, encompassing all the 193 member states of the United Nations since 2016. It derives from a scoring system that uses the arithmetic mean to aggregate indicators relating to each of the 17 SDGs in turn, before 'averaging' the results into a single metric [19]. A system of equal weights is deliberately employed to reflect international commitments ''to treat each SDG equally and as an integrated and indivisible set of goals" (Sachs et al. [29] p. 41). The SDG-I is not intended to replace the global dashboard of indicators for monitoring the SDGs (Sachs et al. [30] p. 32). However, it does have enormous potential (like other well-known composite indicators) for identifying priority areas for action, tracking overall progress, and making international comparisons.

3. Methodology

This research aims to map the relationships between the SDGs, supported on a correlation analysis of the results of 17 SDGs for all the 193 UN member states, selected as the source of data for the subsequent correlation analysis.

Due to its conceptual complexity, it is challenging to translate some of the SDGs into measurable indicators. Moreover, the data is not always available, and some countries have difficulty reporting these indicators with reliability, making it difficult for cross-country comparability, or agreed-upon methodologies for measurement.

To overcome these limitations, and considering its international legitimacy and acceptance, the Sustainable Development Goal Index (SDG-I) [29] was chosen as data source for this analysis. The SDG-I aggregates indicators relate to each of the 17 SDGs and 'average' the results into a single metric. To check data normality, Kolmogorov-Smirnov Test was applied. The results of the K-S normality test highlighted that most SDGs do not follow a normal distribution (Table 3), so correlation coefficient Spearman's Rho (that does not require normally distributed data and provides more robust results) was adopted.

In order to clarify the Kolmogorov-Smirnov test results, the Kernel density (a variation of the histogram) of each SDG variable was plotted. The Kernel density plots are visually depicted as

smoothed curves estimating the probability density function of a continuous variable from a set of scores (likely comprising some error) (Figures 1 and 2).

The correlation coefficient measures the intensity of the relationship between ordinal variables and varies between -1 e 1. As near the values are from these extremes, the stronger is the linear association between the variables. The sign indicates the direction of the association between X (the independent variable) and Y (the dependent variable). If Y tends to increase when X increases, the correlation coefficient is positive. If Y tends to decrease when X increases, the correlation coefficient is negative. If the value is zero, this means there is no linear relationship between the variables. Statistical analysis was carried with SPSS Statistics Version 26, and the overall results, showing the existence of several significant relationships, are presented in Table 4.

4. Results and Discussions

4.1. Kolmogorov-Smirnov Test Results

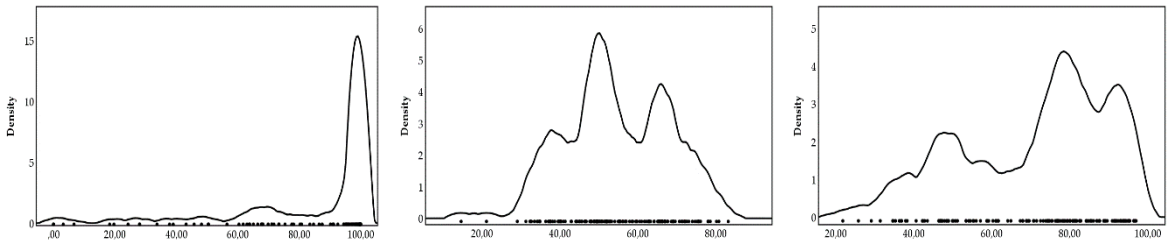
Based on the results presented in Table 3, there is not statistical evidence (considering a p-value<0.05) that the variables SDG8, SDG10, SDG16 and SDG17 do not follow a normal distribution. However, these results do not provide a great deal of information on the actual statistical distribution, so the Kernel densities were plotted (Section 4.2).

Table 3. Kolmogorov-Smirnov test results.

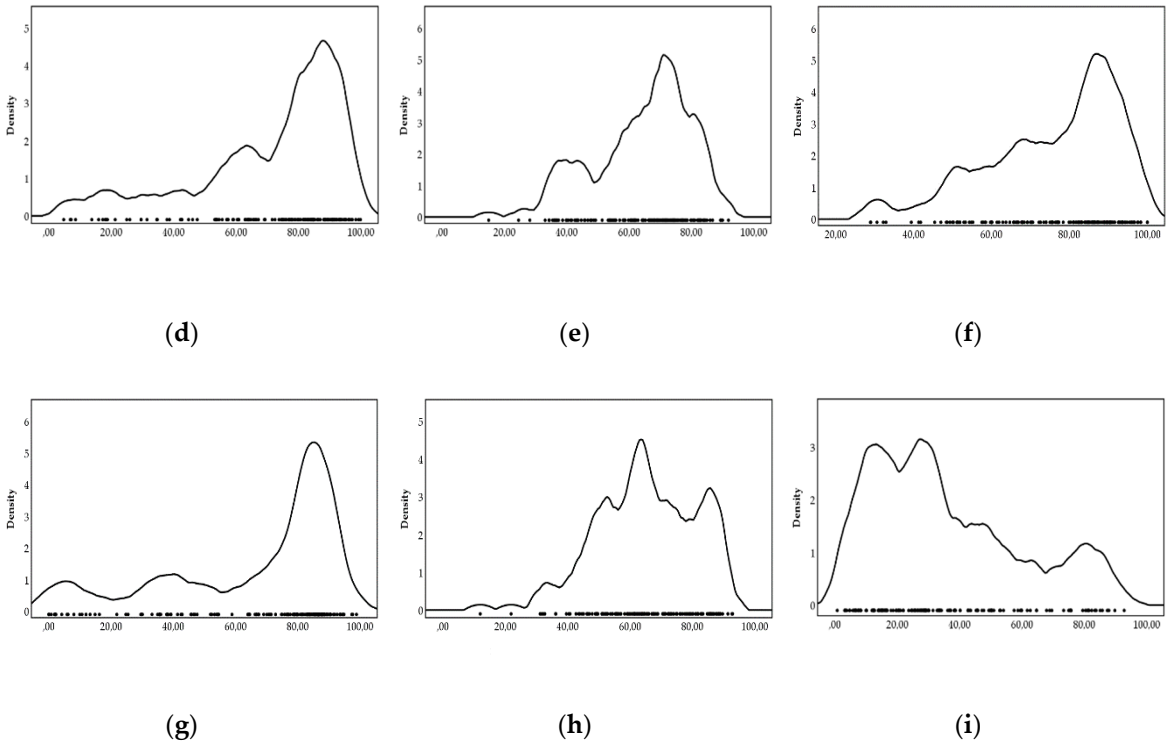
	Sustainability Development Goal																
	G1	**G2**	**G3**	**G4**	**G5**	**G6**	**G7**	**G8**	**G9**	**G10**	**G11**	**G12**	**G13**	**G14**	**G15**	**G16**	**G17**
Test stats	0.322	0.073	0.140	0.166	0.105	0.131	0.215	0.051	0.135	0.065	0.126	0.149	0.172	0.132	0.035	0.060	0.087
Sig. (bilateral)	0.000	0.042	0.000	0.000	0.000	0.000	0.000	0.200	0.000	0.200	0.000	0.000	0.000	0.000	0.200	0.200	0.006

4.2. Kernel Density and Rug Plots

Figures 1 and 2 present the Kernel density plots and the rug plots for each SDG. It is possible to highlight that SDG1 (Figure 1a.) is the benchmark based on the latest available results, i.e., a high density of countries report scores near the upper limit of the scale (positive asymmetry). Concerning the SDG8 (K-S test did not rule out a normal distribution) (Figure 1.h), it is possible to observe that, indeed, the statistical distribution is not so asymmetric as the other variables in Figure 1 but a multimodal feature seems to be present. In addition, the visual representation of the data supported on the Kernel density function suggests that SDG9 (Figure 1i) presents the worst scores, i.e., a relevant negative asymmetry.



(**a**) (**b**) (**c**)

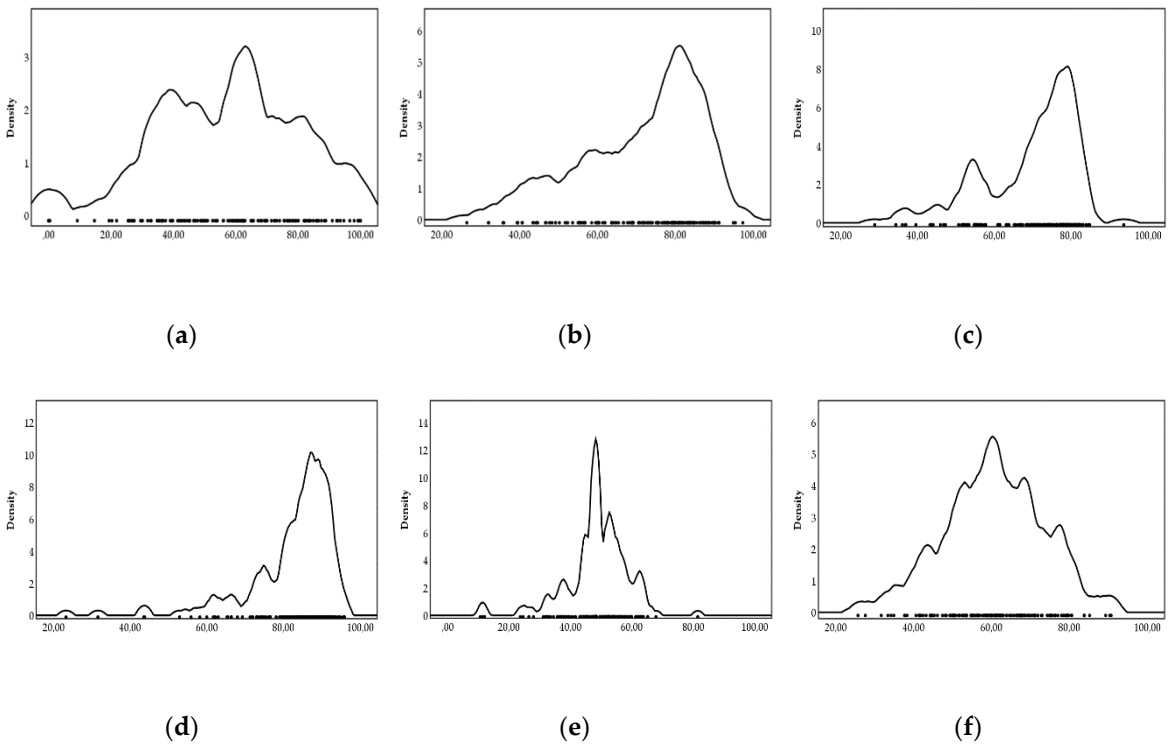


(**d**) (**e**) (**f**)

(**g**) (**h**) (**i**)

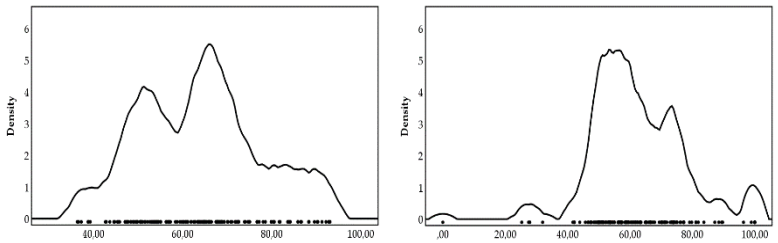
Figure 1. Kernel density and rug plots: (**a**) SDG1; (**b**) SDG2; (**c**) SDG3; (**d**) SDG4; (**e**) SDG5; (**f**) SDG6; (**g**) SDG7; (**h**) SDG8; (**i**) SDG9.

Concerning Figure 2 (variables SDG 10 - figure 2a to SDG 17 – figure 2h), it is possible to observe that, although the K-S test did not ruled out a Gaussian distribution regarding variables SDG10, SDG 15 and SDG 16, the actual statistical distribution seems to encompass several modes. In addition, a great deal of the statistical distributions depicted seem to present a positive asymmetry.



(**a**) (**b**) (**c**)

(**d**) (**e**) (**f**)



(**g**) (**h**)

Figure 2. Kernel density and rug plots: (**a**) SDG10; (**b**) SDG11; (**c**) SDG12; (**d**) SDG 13; (**e**) SDG14; (**f**) SDG15; (**g**) SDG16; (**h**) SGD17.

4.3. Correlation Analysis

The results of the correlation analysis identified several significant correlations between the SDGs, as presented in Table 4. With the purpose of allowing for an overall overview of the phenomenon, the correlation coefficients' levels were classified according to the literature, as shown in Table 5 (Hinkle, Wersma and Jurs, [31]) and coded with colors for easy identification.

Table 4. SDGS correlation analysis.

	SDG1	SDG2	SDG3	SDG4	SDG5	SDG6	SDG7	SDG8	SDG9	SDG10	SDG11	SDG12	SDG13	SDG14	SDG15	SDG16	SDG17
SDG1	1.000	0.609**	0.734**	0.670**	0.338**	0.357**	0.661**	0.578**	0.686**	0.424**	0.466**	−0.570**	−0.177*	−0.007	−0.164*	0.599**	−0.103
SDG2	0.609**	1.000	0.821**	0.776**	0.595**	0.595**	0.745**	0.741**	0.796**	0.391**	0.623**	−0.675**	−0.095	0.170*	0.042	0.590**	−0.028
SDG3	0.734**	0.821**	1.000	0.857**	0.612**	0.501**	0.840**	0.784**	0.892**	0.372**	0.711**	−0.789**	−0.179*	0.180*	−0.053	0.736**	−0.032
SDG4	0.670**	0.776**	0.857**	1.000	0.655**	0.542**	0.773**	0.731**	0.811**	0.341**	0.712**	−0.705**	−0.164*	0.215**	0.030	0.646**	−0.018
SDG5	0.338**	0.595**	0.612**	0.655**	1.000	0.612**	0.503**	0.626**	0.577**	0.131	0.714**	−0.485**	−0.083	0.223**	0.061	0.313**	0.116
SDG6	0.357**	0.595**	0.501**	0.542**	0.612**	1.000	0.480**	0.494**	0.417**	0.053	0.629**	−0.416**	0.033	0.120	0.031	0.140	0.149
SDG7	0.661**	0.745**	0.840**	0.773**	0.503**	0.480**	1.000	0.611**	0.785**	0.291**	0.655**	−0.673**	−0.034	0.175*	−0.061	0.572**	0.050
SDG8	0.578**	0.741**	0.784**	0.731**	0.626**	0.494**	0.611**	1.000	0.752**	0.290**	0.620**	−0.653**	−0.164*	0.193*	−0.033	0.610**	−0.159*
SDG9	0.686**	0.796**	0.892**	0.811**	0.577**	0.417**	0.785**	0.752**	1.000	0.332**	0.665**	−0.775**	−0.208**	0.240**	0.002	0.741**	−0.090
SDG10	0.424**	0.391**	0.372**	0.341**	0.131	0.053	0.291**	0.290**	0.332**	1.000	0.125	−0.243**	−0.070	−0.011	0.105	0.452**	−0.065
SDG11	0.466**	0.623**	0.711**	0.712**	0.714**	0.629**	0.655**	0.620**	0.665**	0.25	1.000	−0.608**	−0.079	0.263**	-0.026	0.450**	0.097
SDG12	−0.570**	−0.675**	−0.789**	−0.705**	−0.485**	−0.416**	−0.673**	−0.653**	−0.775**	−0.243**	−0.608**	1.000	0.324**	-0.196*	0.069	−0.570**	0.029
SDG13	−0.177*	−0.095	−0.179*	−0.164*	−0.083	0.033	−0.034	−0.164*	−0.208**	−0.070	−0.079	0.324**	1.000	−0.012	0.179*	−0.240**	−0.018
SDG14	−0.007	0.170*	0.180*	0.215**	0.223**	0.120	0.175*	0.193*	0.240**	−0.011	0.263**	−0.196*	−0.012	1.000	0.152	0.110	0.059
SDG15	−0.164*	0.042	−0.053	0.030	0.061	0.031	−0.061	−0.033	0.002	0.105	−0.026	0.069	0.179*	0.152	1.000	−0.014	−0.047
SDG16	0.599**	0.590**	0.736**	0.646**	0.313**	0.140	0.572**	0.610**	0.741**	0.452**	0.450**	−0.570**	−0.240**	0.110	−0.014	1.000	−0.101
SDG17	−0.103	−0.028	-0.032	−0.018	0.116	0.149	0.050	−0.159*	-0.090	−0.065	0.097	0.029	−0.018	0.059	−0.047	−0.101	1.000

* Statistical significant at 0.1 level; ** Statistical significant at 0.05 level.

Note: see Table 5 below for explanations on the background colors grade.

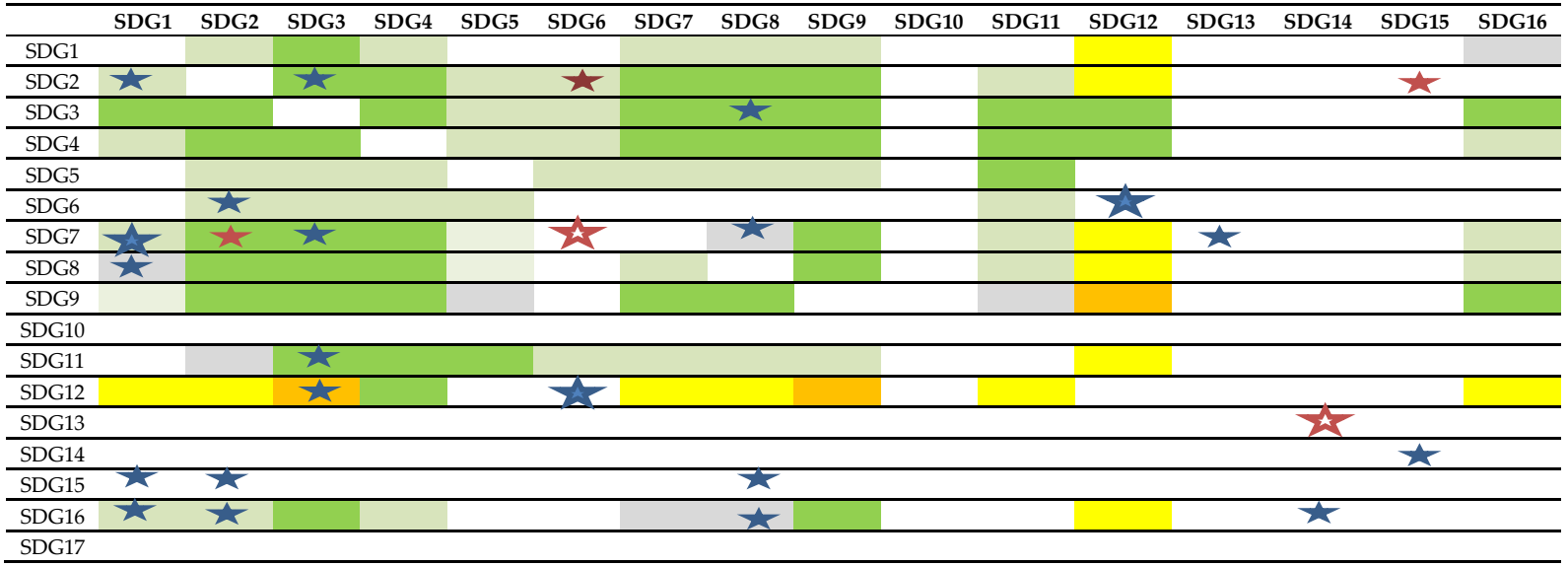
Table 5. Correlation levels classification.

Correlation coefficient	Correlation level	Color grade
0.9 to 1 (–0.9 to –1)	Very strong positive (negative) correlation	Dark green (red)
0.7 to 0.9 (–0.7 to –0.9)	Strong positive (negative) correlation	Green (orange)
0.5 to 0.7 (–0.5 to –0.7)	Moderate positive (negative) correlation	Grey (yellow)
0.3 to 0.5 (–0.3 to –0.5)	Weak positive (negative) correlation	No color
0.0 to 0.3 (0 to –0.3)	Inexistent correlation	No color

Source: Hinkle, Wersma and Jurs [31].

Based on a meta-analysis of 65 global assessments comprising United Nations reports and international scientific assessments, and 112 scientific articles published since between 2015 and 2019 with explicit reference to the Sustainable Development Goals, the UN's "The Future is Now: Science for Achieving Sustainable Development" report [28], identified a set of interactions (co-benefits to be harnessed) among the SDGs and the relative importance of the potential trade-offs among the SDGs. This analysis supports the view that there is a dominance of positive over negative interactions between the SDGs. However, there are significant gaps in knowledge. The result of this analysis is summarized in Table 6 below, overlapping the previous correlation analysis of Table 4 with the synoptic presented in Table 7.

Table 6. SDGs correlation analysis and UN (2019) SDGs' interactions [28] (x axis influenced, y axis influencing goals) overlap analysis.



note:. Please see Table 5 above for explanation concerning the cell color grade, and Table 7 below for the explanations concerning the star size and color.

Table 7. Legend for interaction between SDGs (UN, 2019 [28]).

Type of interaction	Symbol
Co-benefits to be strongly harnessed	
Co-benefits to be harnessed	
Requires trade-offs	
Strongly requires trade-offs	

Note: the star color and size represent the nature (co-benefits or trade-offs) and the intensity (strongly or average) of the SDGs interactions, as expressed in this table.

These results highlight that there is indeed dominance of positive over negative interactions between the SDGs, which is in line with "The Future is Now: Science for Achieving Sustainable Development" report [28]. The results also indicate that SDG2 (Zero hunger), SDG3 (Good health and well-being), SDG4 (Quality education), SDG7 (Affordable and clean energy), SDG8 (Decent work and economic growth), SDG9 (Industry, innovation, and infrastructure) and SDG11 (Sustainable cities and communities), present the highest number of strong positive correlation with other SDGs. While concerning trade-offs, SDG12 (Responsible consumption and production) is the one that shows more strong and moderate negative correlations with other SDGs.

5. Conclusions

The literature review and the assessment of the SDGs' relationships confirm that there are indeed relevant interactions between the SDGs. However, the existence of blind spots recommends the need for further research on those interactions. While positive, the interactions between the SDGs are more numerous than the negative ones, considering such a complex system of relationships, synergies, and trade-offs represent a challenge for planners and decision-makers. In support of this view, the IPPC simulations show that there is no simulation where all the SDGs are reached [32]. Nevertheless, the relationships identified in these investigations represent an opportunity for policy and decision-makers, by suggesting the frequently linear development paths of economic growth ahead of social equity and environmental protection might be challenged by other systemic approaches, that offer multiple solutions and drivers for different contexts, as suggested by Biggeri et al. [19].

Barbier and Burgess [10] recommend prioritizing SDGs associated with the highest monetary returns and contributions to social welfare, e.g., childhood health, that generates significant returns due to long-term gains. Another possible approach is to prioritize the conservation of supporting ecosystems to avoid irreversible effects (e.g., actions to address climate change and global warming), and then optimize socio-economic goals taking into consideration the environmental constraints. Breuer et al. [33] identified several models and approaches that can support policy-makers to prioritize the SDGs. The World in 2050 model [34] conceptualizes the SDGs as delineated by the planetary boundaries, with global partnerships for sustainable development (SDG17) and governance (SDG16) providing the framework for the other SDGs, clustered into five main categories of SDGs: social and economic development (SDGs 8, 9, 11), universal values (SDGs 4, 5, 10), basic human needs (SDGs 1, 2, 3), and sustainable resource use (SDGs 6, 7, 12). However, the priorities can change within different development contexts, e.g., basic conditions of life in more developing countries, or sustainable resource use in more developed ones. Other simulation models like the World Economic Forecasting Model (WEFM), the iSDG model, developed by the Millennium Institute, can also support decision-makers and civil society stakeholders to visualize the long-term

trajectory of their country's current development path and help them to devise coherent alternative policies that are better suited to achieving the SDGs [33].

At the micro level, organizations emphasize the need to adopt more flexible and innovative approaches with a more substantial open systems perspective (influence of the environment, dynamic environment, need for survival), e.g., within those that adopt ISO International Standard Management Systems [35]. Moreover, authors such as Domingues et al. [36], Poltronieri et al. [37], and Rebelo et al. [38], stress the need for a systemic approach while reporting the efforts carried out to operationalize this integration process among the organizations, taking into account the needs and expectations of the stakeholders. The adoption of systemic and integrated approaches is, therefore, recommended at both the macro and the micro level to contribute to the SDGs.

Specifically concerning the correlation study, the results support Pradhan et al.'s [21] conclusions that Poverty elimination (SDG1) and health and well-being (SDG3) have a synergetic relationship with most of the other goals. There is also confirmation that SDG12 (Responsible consumption and production) is the goal most associated with trade-offs.

Accordingly, with the literature, SDG7 (Affordable and clean energy) has a significant relationship with other SDGs (e.g., SDG1 (No poverty), SDG2 (Zero hunger), SDG3 (Good health and well-being), SDG8 (Decent work and economic growth) and SDG13 (Climate action)), requiring coordinated policy interventions to protect the vulnerable, ensure equity and manage competing demands over natural resources to support sustainable development [26,28]. The correlation study confirmed the existence of strong positive correlations between SDG7 and SDG2 (Zero hunger), SDG3 (Good health and well-being), SDG4 (Quality education) and SDG9 (Industry, innovation, and infrastructure), highlighting the importance of the access to affordable and clean energy for economic, environmental and social performance. However, there is a moderate negative correlation with SDG12 (Responsible consumption and production), which emphasizes the need to improve energy efficiency, increase the share of clean and renewable energies and improve sustainable consumption patterns worldwide.

While there is also consistency between the correlation analysis and the UN study [28], e.g., relating to the relationships addressing synergies between SDG1 (Zero hunger), SDG01 (No poverty) and SDG3 (Good health and well-being), no significant relationships between SDG13, SDG14, SDG15 and SDG17 with other SDGs was found. Particularly in the case of SDG13 (Climate action), it is surprising no significant correlation with other SDGs was found. This is in line with Stafford-Smith et al. [13] who argue that there are still open issues regarding SDG performance measurements, operationalization, and interlinkages.

Relating to the existence of negative relationships (trade-off), the correlation result supports Pradhan et al. [21], since SDG12 (Responsible consumption and production) is the goal most associated with trade-offs. However, the trade-offs identified in the UN study [28] are not confirmed by the correlation results.

An overall conclusion is that effective action for the advancement of the SDGs and, ultimately, sustainable development for all, demands that the relationships between the SDGs must be identified and tackled, e.g., the connections between No poverty and Zero hunger, and Good health and well-being, or between climate change and human health. This should lead to the increased relevance of SDG17 (Partnerships for the goals) and more intense and effective cooperation between governments, institutions, agencies, private sector and public organizations, and society at large, across different industries, locations, and levels.

A common support of that relevance is developing a sustainable intellectual capital [39], based on knowledge dynamics [40], at the organizations' and communities' levels.

To sum up, this research suggests that change towards achieving the Sustainable Development Goals offers many opportunities for reinforcing rather than inhibiting itself. Moreover, as The World Health Organization (WHO) declared a public health emergency of international concern over the global outbreak of COVID-19 (30th January 2020) and escalated it to a global pandemic on 11th March 2020 [41], we are once more reminded that we do live in one global and interconnected world. Hence the relevance of the SDGs' framework. The limitation of the correlation analysis, and the potential

problems related to the use of an index based on the arithmetic mean (which assumes that different targets and indicators are perfect substitutes for each other, without accounting for positive synergies or negative externalities, as stated by Biggeri et al. [19]) should be acknowledged. These limitations recommend the replication of this investigation with more powerful statistical techniques and a longitudinal perspective.

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