Complexity Measures for the Analysis of SDG Interlinkages: A Methodological Approach

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Abstract: The 2030 Agenda, with its 17 Sustainable Development Goals (SDGs), 169 targets and 232 indicators, has set an ambitious "plan of action for people, planet and prosperity"1 that must be achieved within 15 years (2015-2030). These first years of implementation of the SDGs by the 193 member states of the United Nations (UN) have served the international community to realize the complexity of the network of interactions (synergies and trade-off) between goals, targets and indicators, within a context where each country has set its priorities of development and those are not always aligned with the main objective of the 2030 Agenda (lack of policy coherence; policy vs politics). As a result of this situation, one of the main difficulties that the countries will need to overcome is to comprehend the nature and complexity of the intricate network of interlinkages between the SDGs, considering their universal and integrated nature. The purpose of this study is to improve the understanding of the level of sustainability complexity of each member state of the UN in the process of the implementation of the SDGs based on the Product-Space Theory and the Economic Complexity. Thus, we present a SDG priority-setting tool applied to the challenging and ambitious task of accomplishment of the 2030 Agenda, through the understanding of the SDG interlinkages network and its complexity. Our findings are significant for the on-going debate of policy coherence and alignment of national policies with the SDGs and the sustainability path countries should follow to progress towards an integral achievement of the 2030 Agenda.

1 INTRODUCTION

The 2030 Agenda, with its 17 Sustainable Development Goals (SDGs), 169 targets and 232 indicators, has set an ambitious "plan of action for people, planet and prosperity" that must be achieved within 15 years (2015-2030) (UN, 2015). These first years of implementation of the SDGs by the 193 member states of the United Nations (UN) have served the international community to realize the complexity of the network of interactions (synergies and trade-off) between goals, targets and indicators, within a context where each country has set its priorities of development and those are not always aligned with the main objective of the 2030 Agenda (lack of policy coherence; policy vs politics).

In this context, countries members have begun to send their Voluntary National Reviews (VNRs) to the High-Level Political Forum on Sustainable Development of the United Nations with their performances and experiences in the implementation of the SDGs at the national level (UN, 2016).

In this process of sharing the first results, experiences, and difficulties on the 2030 Agenda implementation, it has been evidenced that key gaps and doubts remain in the understanding on the SDGs interactions and their individual impact (influence and dependence) in the whole SDG system (UN, 2016).

The main difficulties that countries, will need to overcome is to understand the nature and impact (synergies and trade-offs) of the interlinkages between the different targets at the national level, considering the universal and integrated nature of the

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SDGs and that the decisions made by the country in a specific goal will necessarily have an effect (positive, negative, or neutral) in the achievement of the other SDGs and in the probability as a country to accomplish the full 2030 Agenda.

As many experts have underlined, in this global scenario and facing the complexity and universality of the SDGs, a priority setting for the implementation of the 2030 Agenda is recommended (Allen et al., 2018; Allen et al., 2018a; Weitz et al., 2018; Zelinka & Amadei, 2019; McGowan et al., 2018), in order to: improve the qualitative and quantitative understanding on SDGs interactions; identify direct and indirect effects of SDGs interactions; detect patterns on SDGs interactions; identify critical goals and targets (central nodes) in the SDG network; and secondary analyses to increase synergies and avoid trade-off in the implementation of the 2030 Agenda and its alignment with the national plans of development (UN, 2014).

The aim of this study is to propose a new methodological approach for the analysis of the SDG interlinkages and the progress of the countries in the implementation of the 2030 Agenda, based on their accumulated sustainability capabilities measured through the use of complexity measures and network theory.

This paper is organized as follow: first, in Section II a brief account of state-of-the-art literature on Sustainable Development Goals (SDGs) and SDG interlinkages analysis is made. Then, in Section III the methodology, based on the economic complexity and the product space theory to evaluate the SDG interlinkages is explained. Third, in Section IV, we show the results and discussion of our analyses, including the interpretation of the findings.

Finally, in Section V, the conclusions are presented.

2 LITERATURE REVIEW

The UN Sustainable Development Goals (SDGs) were adopted in September 2015 by the 193 United Nations (UN) member states, in a document called "Transforming our world: the 2030 Agenda for Sustainable Development". The SDGs with its 17 goals, 169 targets and 244 indicators, try to leave behind the siloed approach applied by the countries in the past, to propose an "indivisible and integrated" agenda, focusing on the 3 dimensions of the sustainable development: social, economic, and environmental (UN, 2015). Additionally, the 2030 Agenda also considers the 5P (people, planet, prosperity, peace, partnerships) as key elements for delivering the SDGs.

These goals are a result of a major multilateral and intergovernmental cooperation through a participatory process that included the work of (UN, 2014), with the purpose of filling the gaps from the Millennium Development Goals (MDGs) that were less ambitious and more focused on poverty and water sanitation issues (Le Blanc, 2015; Vladimorova & Le Blanc, 2016; Gusmao et al., 2018).

Achieving this highly ambitious agenda will require not only political commitment, but also important global investments of approximately 5-7 trillion USD per year (2015-2030) according to estimations of (UNCTAD, 2014).

At the moment of writing this paper, there are already available, at the Sustainable Development Knowledge Platform, 227 documents reporting the national voluntary reviews of the implementation of the SDGs. These reviews have revealed the difficulties of countries to implement the 2030 Agenda and the need of a better understanding of the interactions between goals, targets, and indicators in order to take advantage of the synergies and to improve policy coherence (UN, 2016; Allen et al., 2018; Allen et al., 2018a; Weutz et al., 2018).

2.1 The "Indivisible and Integrated" Nature of SDGs

In the last years it can be observed an increase of the literature related to assessment, analysis and evaluations of the interlinkages between the SDGs, covering different approaches and using a diversity of methodological tools for SDG interactions.

As mentioned by (McGowan et al., 2018), "*... the indivisible nature of the SDGs is widely advanced as axiomatic and underpins assessments of policy coherence*". Therefore, the analysis of SDG interlinkages offers fundamental information for policymakers, guiding (through validated data) the decision-making and the policy-design, aligned with the sustainable development pillars.

Since the beginning of the implementation of the 2030 Agenda, the main part of the literature focused on the study of the impact of one specific goal and its interaction with the other goals or development priorities (Vladimorova & Le Blanc, 2016, Alcamo, 2019; Nerini et al., 2017).

In the following years, the analysis of interactions between goal sub-groups and the rest of the SDGs have gained more relevance in the literature, in an approach that is known as the "nexus approach". Under this approach it can be found a wide range of studies, analyzing different combination of goals (nexus combinations), for example: water-energy-food nexus, energy-poverty-climate nexus, etc. (Liu et al, 2018; Bleischwitz et al, 2018; Dargin et al., 2019; Karnib, 2017).

Alternatively, with the purpose of improving the comprehension of the interactions (synergies and trade-off) between goals and targets, a new approach appeared, based in more quantitative and data visualization methods for the different analysis, known as: network analysis (Allen et al, 2018; Allen et al, 2018a; Weitz et al., 2018; Zelinka & Amadei, 2019; McGowan et al, 2018; Le Blanc, 2015; Pedrosa-Garcia, 2018; Lusseau & Mancini, 2018).

Nevertheless, despite the existence of several approaches, methods and studies about the SDG interlinkages, there are still many questions as: which is the real impact of the potential synergies and trade-off at the different SDG levels (goals, targets and indicators)?; which mechanisms intervene in those interactions?; what is the impact of neutral interactions?; how can be quantified the potential impact of synergies and trade-off?; etc. (Nerini et al., 2017; Nilsson et al., 2016; Nilsson et al., 2018; Maes et al., 2019 : McCollum et al., 2018; Moyer & Bohl, 2019; Scherer et al., 2018; Singh et al., 2018).

2.2 SDGs Network System Analysis

Considering the universality, the diversity of sectors and stakeholders involved in the implementation of the 2030 Agenda, it becomes necessary for countries the identification of priorities within the SDGs (Allen et al, 2018; Weitz et al., 2018; McGowan et al., 2018; Alcamo, 2019; Nilsson et al., 2016; Scherer et al., 2018; Singh et al., 2018). As stated by (McGowan et al., 2018), the selection of priorities reflects the strategy and policy criteria of each country (expressed by its policymakers) to evaluate the level of urgency in each sector.

The pioneer study in this field related to the SDGs was the one from (Le Blanc, 2015) that, even if it was criticized for the superficiality of the wording reference methodology implemented to analyze the interactions between SDG and mapping its interlinkages network. Then, (Vladimorova & Le Blanc, 2016) have presented and analysis of 37 official reports from the United Nations to evaluate the interactions between education and SDGs, based again on the wording reference methodology. In this case, the results have shown low levels of interactions between education and the SDGs related to energy, health and responsible consumption and production.

Applying the network approach and reinforcing the results presented by (Le Blanc, 2015) about the asymmetry of the interlinkages between the SDGs, (McGowan et al., 2018) highlight that those interlinkages are uneven, observing the lack of connections between critical SDGs as those related to gender equality, peace and governance. These authors have based their analysis on the report from the (Griggs et al., 2017) and based on the interactions identified on it from a science-based perspective (ICSU, ISSC, 2015), they constructed a SDG network of interactions considering 4 main elements: degree (number of links per node), strength (total number of links from a node), closeness (distance with other nodes in the network and centrality of a node in the network), betweenness (flow of information through the network).

Similarly, (Allen et al., 2018) and (Allen et al., 2018a) have implemented a network approach for the analysis of SDG targets interlinkages for 22 Arab countries, based on the methodology of (Nilsson et al., 2016) for the evaluation of the intensity of the interactions (from -3 to +3), through a cross-impact matrix to identify synergies, trade-off, and neutral interactions. The SDG network obtained as a result of the implementation of this methodology considers to 2 network metrics: outdegree and closeness centrality. Then, these results have been used as input for the evaluation of policy gaps and a multi-criteria analysis, to set priorities for the Arab region analyzed.

Similarly, based in the same methodology (Weitz et al., 2018) have evaluated the interactions between 34 SDG targets, obtaining results that reinforce the hypothesis that there are more synergies than trade-off in the SDG network, but in which the trade-off represents a serious threat for the accomplishment of the 2030 Agenda worldwide. Moreover, the SDG network obtained has a deeper level of analysis compared to the study from (Allen et al., 2018), showing the directionality of the interactions between SDG targets, type of interactions, intensity of the influence of targets in the SDG network, the clusters of SDG targets in the network, etc.

Finally, one of the most recent study in the SDGs network system approach is the proposed by (Lusseau & Mancini, 2018), which analyzed how the main interactions of synergy and trade-off at the goal and target levels vary according to the level of income of countries, showing the existence of unstable networks composed by antagonistic subgroups, where the identification of development of priorities in each country is needed.

2.3 Evolution in the Understanding of SDG Interlinkages

In this context, several authors have begun to focus the analysis in the progress of countries in the accomplishment of the SDGs, through rankings (by goals, targets or indicators), qualitative methodologies, traffic light approaches, and many others (Griggs et al., 2017; ICSU, ISSC, 2015; Sachs et al., 2018; Schmidt-Traub et al., 2017; Salvia et al., 2019), in order to identify critical goals and targets for the sustainable development of the countries.

The measurement made by (Sachs et al., 2018), published annually since 2016 with Bertelsmann Stiftung and the Sustainable Development Solutions Network (SDSN), are the reference at the moment of evaluating the progress in the accomplishment of the SDGs worldwide.

The analysis and evaluation of the SDGs is a very complex task, as it has been already underlined in several studies (Dargin et al., 2019; Karnib, 2017; McCollum, et al., 2018). Therefore, it has been developed new methodologies to facilitate the visualization, identification and understanding of the existing synergies and trade-off between goals, targets, and indicators, in order to broader our vision of the complexity of the SDG network.

One of the most implemented methodology has been the individual analysis of the impact of a goal (directionality, intensity, effect, etc.) over another goal or group of goals, having even some cases of analysis at the target level (Alcamo, 2019; Nerini et al., 2017; Maes et al., 2019).

Studies covering the analysis and evaluation of SDG interlinkages at the indicator level are practically inexistent, because of the complexity of analysis of its interactions, the difficulty to access to reliable, regular, and official SDG indicators data in each country, added to the fact of the low level of understanding that still exist about the impact of the SDG indicators interactions (Taylor et al., 2017).

The results of these studies are relevant for policymakers and stakeholders to comprehend the nature of the SDG interlinkages and to improve the SDG priority setting at the national level (Alcamo, 2019). Nevertheless, even if we still have low understanding of the SDG interactions, the existent literature in this topic have demonstrated that there are more positive interactions (synergies) than trade-off in the SDG network (Weitz et al., 2018; Nerini et al., 2017; Maes et al., 2019).

Additionally, considering the need of including in the analysis the indivisible and integrated nature of the SDGs, studies have incorporated the nexus approach. As mentioned by (Liu et al., 2018), the nexus approach facilitates the identification of synergies between goals, the improvement of policy design and the implementation of policies. Moreover, the nexus approach reduces the "*silo-thinking*" to focus on the synergies of critical resources and the promotion of wellbeing (Liu et al., 2018; Bleischwitz et al., 2018; Dargin et al., 2019; Karnib, 2017).

Then, authors using the nexus approach underline that the simple analysis of the type of interaction (synergy or trade-off) is not enough, and it must be complemented with the understanding of the impact of the direct and indirect interactions of the SDGs (Karnib, 2017).

Even with its limitations, the analysis of interactions between SDGs (at the goal, target or indicator level) are fundamentally important for politics and policymakers, considering that allows the identification of development priorities for the countries, the validation of strategic policies through the alignment with the priority goals and targets identified (policy coherence and policy gaps) and the evaluation of strategies for development at the national level (Allen et al., 2018a), (Le Blanc, 2015; Nerini et al., 2017; Karnib, 2017; Maes et al., 2019; Griggs et al., 2017).

The challenge of understanding the intricate and complex SDG network of interactions have been clearly explained by (Weitz et al., 2018), which have expressed: "*Understanding interactions between targets requires quite detailed information, but it also requires the ability to maintain a holistic view of the system as a whole, since it is possible that one policy change can change the dynamics of the whole system*".

2.4 Product-Space

The Product-Space (PS) has been applied in the several studies focused on the analysis of growth opportunities and the level of sophistication of a country´s exports, in order to identify productive capabilities, based on the revealed comparative advantages (RCA) of the products made in each country. Some examples include the case study of Peru, Colombia, Uruguay, Paraguay, Panama, Kazakhstan, China, United States, Sub-Saharan Africa, among others (Hausmann & Klinger, 2008; Hausmann & Klinger, 2008a; González et al., 2019; Ourens, 2012; Vaillant & Ferreira-Coimbra, 2009; Felipe & Hidalgo, 2015; Hausmann et al., 2016; Abdon & Felipe, 2011).

Recently, a new approach proposed by (El-Maghrabi et al., 2018) emerged, applying the PS and the notions of Economic Complexity to prioritize the SDGs and to evaluate the probability of countries of becoming an over-achiever in a particular SDG indicator. The hypothesis proposed by the authors suggest that the probability of achieving a particular SDG target can be estimated conditionally on the observed progress on all the other targets. At the moment, this is the only study implementing this approach in the field of SDGs and the 2030 Agenda.

The PS, based on world export data, is a tool that allows the identification of the probability to produce a product A with RCA, given that it is produced a product B with RCA. Then, the PS network shows the relationship between the capabilities needed to produce each pair of products (Hausmann et al., 2011).

In resume, this theory suggest that countries should take advantage of their current productive capabilities, diversifying their exports basket and increasing its complexity by the development of new products and industries that use capabilities similar to those they already have, facilitating the development of new capabilities and the production of more complex and higher added value goods (González et al., 2019; Abdon & Felipe, 2011; Hidalgo & Hausmann, 2009).

In practice, the PS provides, as mentioned by (Hausmann et al., 2011), the easier and less risky paths through which productive knowledge is accumulated for each country under study. In other words, this approach helps countries to identify products that require similar capabilities to those that a country already have and therefore, have higher probabilities to be produced and co-exported (if the country decides to do it) (Hausmann et al., 2011; Hidalgo & Hausmann, 2009; Hausmann & Klinger, 2007; Hausmann et al., 2014; Hidalgo & Klinger, 2007; Hausmann et al., 2007; Hausmann & Hidalgo, 2011).

The representation of the resulted network of products exported worldwide by countries is called "Product Space", translating global trade data in a network of nodes and edges (Hausmann et al., 2011; Hidalgo & Hausmann, 2009). In its original model, the nodes represent the different products traded worldwide, the sizes of the nodes are proportional to the volume of participation of each product in world trade, while the classification of the products are expressed through the colors of the nodes (Hausmann et al., 2011).

The distance between nodes (links) are determined by the proximity. The proximity (ϕ) represents the conditional probability that a country that exports product p also exports product p´.

There are 2 main elements to be considered in the implementation of this methodology. First, the RCA in a product p, that according to (Balassa, 1965) is achieved if the country exports the product p with a share that is equal to the share of total world trade that the product represents (Hausmann et al., 2011; Balassa, 1965).

$$RCA\ (A_i) = \frac{\frac{x_{iA}}{x_A}}{\frac{x_{iW}}{x_W}} \tag{1}$$

Where X_{iA} represents exports of good i of country A, X_A is the total exports of country A, X_{iw} the world exports of good i, and X_W total. If RCA $(A_i) \geq 1$, then the product i of country A has revealed comparative advantage otherwise it has not.

Higher levels of RCA are understood as higher level of competitiveness in the international market.

Second, the Proximity, that according to the literature, represents the idea that 2 products that need similar capabilities or productive knowledge have higher probabilities to be co-exported or produced in tandem, while products that need more different capabilities have lower probabilities to be produced together or to be co-exported. Then, it should be easier for countries to improve their productive structure by making shorts steps towards near products in the product-space network (Hausmann et al., 2011; Hidalgo & Hausmann, 2009; Hidalgo et al., 2007).

Mathematically, the proximity between 2 products, "i" and "j", can be calculated as the minimum distance between the probability that countries can export a product "i" with RCA, since they export the good "j" with RCA and the probability of countries exporting a "j" good with RCA, since they export product "i" with RCA:

$$\phi_{ij} = \min\{P(VCR_i \geq 1 \mid VCR_j \geq 1),\ P(VCR_j \geq 1 \mid VCR_i \geq 1)\} \tag{2}$$

The proximity matrix is constructed using the results from the RCA analysis as inputs, showing a matrix of countries and products, where a value of 1 is given if product p for a given country c has RCA≥1 or 0 (zero) otherwise. Then, the "Mcp" matrix can be expressed as follows (Hausmann et al., 2011):

$$M_{cp} = \begin{cases} 1 & if\ \ RCA_{cp} \geq 1 \\ 0 & if\ RCA_{cp} < 1 \end{cases} \tag{3}$$

Finally, the proximity measure, understood as the conditional probability that a country that exports a product p, will also export a product p', is calculated based on the previously mentioned M_{cp} matrix. Formally, the proximity of a pair of products "pp´" can be expressed as follows (Hausmann et al., 2011):

$$\phi_{pp'} = \frac{\Sigma_c M_{cp} M_{cp'}}{\max(K_{p,0}, K_{p',0})} \quad (4)$$

2.5 Complexity Measures

The economic complexity it is related with the ubiquity and diversity of the accumulated knowledge in a determined economy. Then, in a specific country, as more people from different sectors interact, combining their knowledge to produce a diversity of products, a more complex economy could be expected. Therefore, the economic complexity can be expressed as the share of productive knowledge accumulated by a country, as a result of using and combine that knowledge (Hausmann et al., 2011).

The knowledge can be only accumulated, transferred and preserved if it is incrusted in a people´s network or in organizations that apply that knowledge for productive purposes. If producing a product requires a specific type or combination of knowledge, then the countries that produce that product reveal that they have the capabilities and required knowledge to produce it (Hausmann et al., 2011).

The economic complexity of a country is reflected in the amount of productive knowledge of its economy, measured by the use of 2 main indicators, the diversity and the ubiquity.

The diversity it refers to the amount of products produced in a specific country, while the ubiquity refers to the amount of countries that produce a specific product.

$$Diversity = Kc,0 = \sum_p Mcp \quad (5)$$

$$Ubiquity = Kp,0 = \sum_c Mcp \quad (6)$$

In order to generate a more accurate measure of the number of available capabilities of a country, or the required capabilities for a product, it is necessary to correct the information that the diversity and ubiquity hold, through the use of each of them to correct the other, and vice versa. As proposed by (Hausmann et al., 2011), this can be expressed as the following equations:

$$Kc,N = \frac{1}{Kc,0} \sum_p Mcp \times Kp,N-1 \quad (7)$$

$$Kp,N = \frac{1}{Kp,0} \sum_c Mcp \times Kc,N-1 \quad (8)$$

$$Kc,N = \frac{1}{kc,0} \sum_p Mcp \times \frac{1}{Kp,0} \sum_{c'} Mc'p \times Kc',N-2 \quad (9)$$

$$Kc,N = \sum_{c'} kc',N-2 \sum \frac{McpMc'p}{Kc,0\; Kp,0} \quad (10)$$

This can be rewritten as follows:

$$K_{c,N} = \sum_{c'} \bar{M}_{cc'} K_{c',N-2} \quad (11)$$

Finally, it can be obtained the following expression:

$$\bar{M}_{cc'} = \sum_p \frac{M_{cp} M_{c'p}}{K_{c,0} K_{p,0}} \quad (12)$$

Note that Eq. 12 it is fulfilled when $K_{c;N} = k_{c;N-2} = 1$. This it is the eigenvector of $M_{cc'}$ that is associated with the highest eigenvalue. The eigenvector is a vector of 1, so it is not informative. It is expected instead, that the eigenvector associated to the second largest eigenvalue, to capture the highest amount of variance of the system. Therefore, the Economic Complexity Index (ICE) is defined as follows (Hausmann et al., 2011):

$$ECI = \frac{\vec{K} - <\vec{K}>}{stdev(\vec{K})} \quad (13)$$

Where, $<\vec{K}>$ is an average, stdev() represents the standard deviation and $\vec{K}$ is the eigenvector of $\bar{M}_{cc'}$ associated with the second largest eigenvalue.

Analogously, it is defined the Product Complexity Index (PCI). Due to the symmetry of the problem, it can be done simply by exchanging the index of country (c) with the products (p) in the before mentioned equations. Then, the PCI can be expressed as follows (Hausmann et al., 2011):

$$ICP = \frac{\vec{Q} - <\vec{Q}>}{stdev(\vec{Q})} \quad (14)$$

Where, $\vec{Q}$ is the eigenvector of $\bar{M}_{pp'}$ associated to the second largest eigenvalue.

3 METHODOLOGY AND MODEL ESPECIFICATION

This research develops an analysis of the interlinkages among the Sustainable Development Goals, through the use of the economic complexity and product space theory, offering a new approach to the study of SDG interlinkages.

Additionally, the methodology applied serves as a tool for policymakers to improve decision-making, facilitating the setting of priorities in the 2030 Agenda at the national level through the analysis of the interlinkages, synergies and trade-off existing in the structure of the SDGs and their impact in policy design and its implementation.

The implementation of the methodology is structured in 2 phases:

- *Revealed Comparative Advantage*: to identify the SDGs with RCA for each country under study. This information will serve as input for the complexity measures.
- *Product-Space Analysis*: to evaluate the SDG network and the interlinkages between goals. Then, to calculate and evaluate the Sustainability Complexity Index (SCI) and the Goal Complexity Index (GCI), and its implications in the prioritization of the SDGs.

3.1 Measure the RCA

In the first stage, through the use of the concepts of the RCA, it has been identified for each of the countries under study, the SDGs that present a "revealed comparative advantage" considering their performances in the accomplishment of the 17 SDGs for the year 2018, according to (Sachs et al., 2018).

As a result of this first stage we have obtained a new matrix of country and goals, known as Mcg matrix, identifying for each country the SDGs with RCA according to their respective level of accomplishment. The Mcg (country-goal) matrix is obtained using the same theoretical framework explained previously, but with the only difference is that we analyze SDGs instead of products.

$$RCA_{Cg} = \frac{\frac{X_{gC}}{X_C}}{\frac{X_{gW}}{X_W}} \tag{15}$$

Where,

X_{gc}: the normalized value of the accomplishment of the SDG "g" in the country "C"

$X_C = \sum_1^g X_{gC}$: Sum of all the normalized values of the accomplishment of all the SDGs in the country "C"

$X_{gW} = \sum_1^C X_{gC}$: Sum of all the normalized values of the SDG "g" in all the countries under study "W".

$X_W = \sum_1^C X_C = \sum_1^g X_{gW}$: Sum of the normalized values of the SDG "g" for all the countries under study "W"

Then, using the M_{cg} matrix as input, we were able to calculate the proximity for each pair of SDGs, which is an important information for the further analysis of complexity measures.

The database used have been extracted from (Sachs et al., 2018) for the 156 countries that provides reliable data for the 17 SDGs of the 2030 Agenda. This database is available at the SDSN website.

3.2 SDG Complexity Analysis

In this stage, based on the complexity measures, the Sustainability Complexity Index (SCI) and the Goal Complexity Index (GCI), it has been analyzed the situation from a different perspective.

First, we identify the level of complexity of countries in the accomplishment of the SDGs through the SCI. In this evaluation, the are 2 elements that must be considered: the ubiquity and the diversity. Considering RCA, it can be express the Mcg matrix (countries vs goals).

$$M_{cg} = \begin{cases} 1 & if\ RCA_{Cg} \geq 1 \\ 0 & if\ RCA_{Cg} < 1 \end{cases} \tag{16}$$

Mathematically, and based on the complexity measures from (Hausmann et al., 2011), the SCI is defined as follows:

$$SCI = \frac{\vec{R} - <\vec{R}>}{stdev\ (\vec{R})} \tag{17}$$

Where $< \vec{R} >$ represents an average, stdev is the standard deviation and $\vec{R}$ is the eigenvector of $\bar{M}_{cc'}$ associated with the second largest eigenvalue.

Second, it has been evaluated the SCI as a tool to predict wellbeing and development of countries, comparing the SCI against different index

Third, based on the results of the GCI, it has been analyzed the complexity of the SDGs, in order the comprehend the nature of each goal and to identify the goals that require more or less sustainability capabilities to be fully accomplished. Formally, and based on the theoretical framework from (Hausmann et al., 2011), the GCI is expressed as:

$$GCI = \frac{\vec{S} - <\vec{S}>}{stdev\ (\vec{S})} \tag{18}$$

Where $< \vec{S} >$ is the eigenvector of $\bar{M}_{gg'}$ associated with the second largest eigenvalue.

4 RESULTS

The Sustainability Complexity Index (SCI) proposed in this study could be an interesting tool to improve the implementation of the 2030 Agenda, considering that it allows to measure the sustainability capabilities that each country has for the accomplishment of the SDGs.

Additionally, we observe that the SCI it is not only related to economic growth, but it is also strongly related to a wide and ambitious variety of critical indicators for the development of the countries, aligned with the integrated and indivisible nature of the SDGs.

In Fig.1, we can observe a strong correlation between GDP per capita and SCI. It must be underlined, that from the first quadrant, the trend line clearly fits an exponential behavior, with highest level of GPD per capita explaining highest levels of SCI.

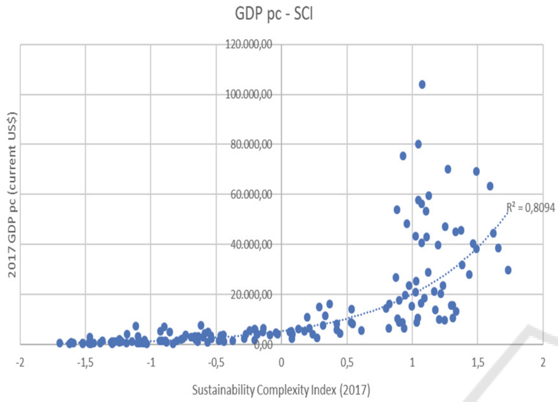

Figure 1: Relationship between SCI and GDP per capita.

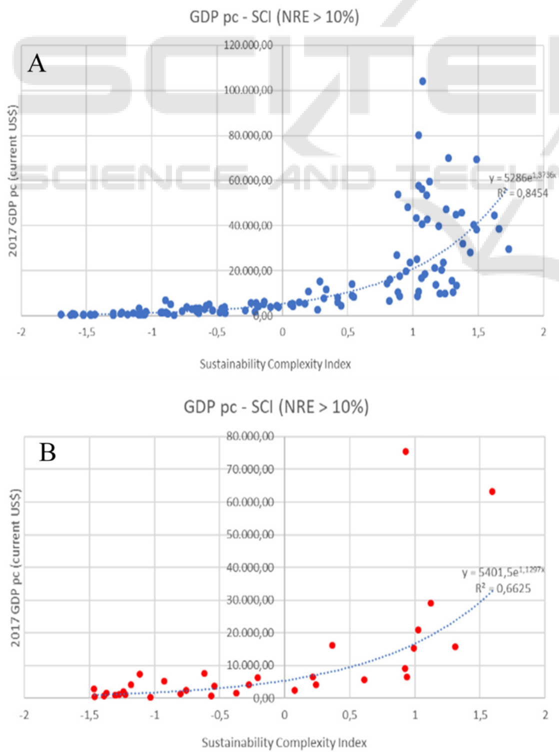

Figure 2: (A) Relationship between GPD per capita and SCI in countries where natural resources exports are lower than 10% of GDP. (B) Relationship between GPD per capita and SCI in countries where natural resources exports are higher than 10% of GDP.

Then, in Fig.2 it has been disaggregated the analysis between exporters and non-exporters of natural resources, based on the groups of countries proposed in (Hausmann et al., 2011).

From Fig. 2A we can infer that GDP per capita it is an optimal proxy of SCI in countries that are not highly dependent on natural resources exports (i.e. oil, natural gas, etc.). In the other hand, the correlation of GPD per capita and SCI it is low to moderate, for countries highly dependents on natural resources exports. This situation could be a secondary effect of what in economics it is known as the *dutch disease*, potentially also affecting the accomplishment of the SDGs.

Furthermore, from other perspective, in Fig. 3 we can observe the relationship between the SCI and the GDP per capita in terms of purchasing power parity (PPP), showing the same exponential behavior, especially for GDP pc (PPP) from 6.000 US$.

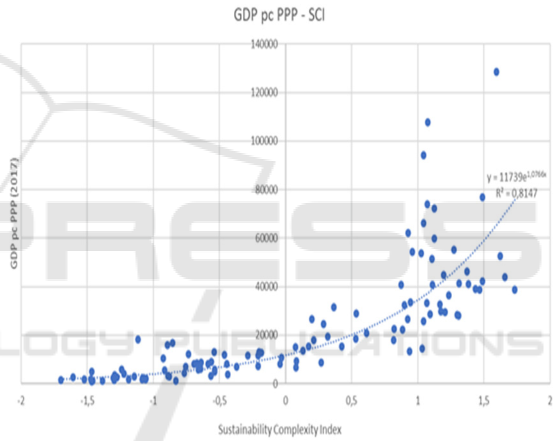

Figure 3: Relationship between SCI and GDP per capita in terms of purchasing power parity (PPP).

Moreover, in Fig. 4 we can distinguish the different levels of correlation between the SCI and a diversity of development index as the SPI, GCI (World Economic Forum), HDI (United Nations) and the WHI (United Nations).

From Figure 4, we observe that SCI shows a good fit, especially with development index that consider different variables and sectors in the analysis, as the SPI, the GCI and the HDI, reinforcing the fact of the universality of the challenges behind the SDGs. In the other hand, the WHI does not seem to be a good explicative variable of the accomplishment of the SDGs.

Additionally, we have also found that the SCI shows a low correlation with the Gini Index (R^2 = 0,14), a moderated level of correlation with the average years of education (0,56) and low to

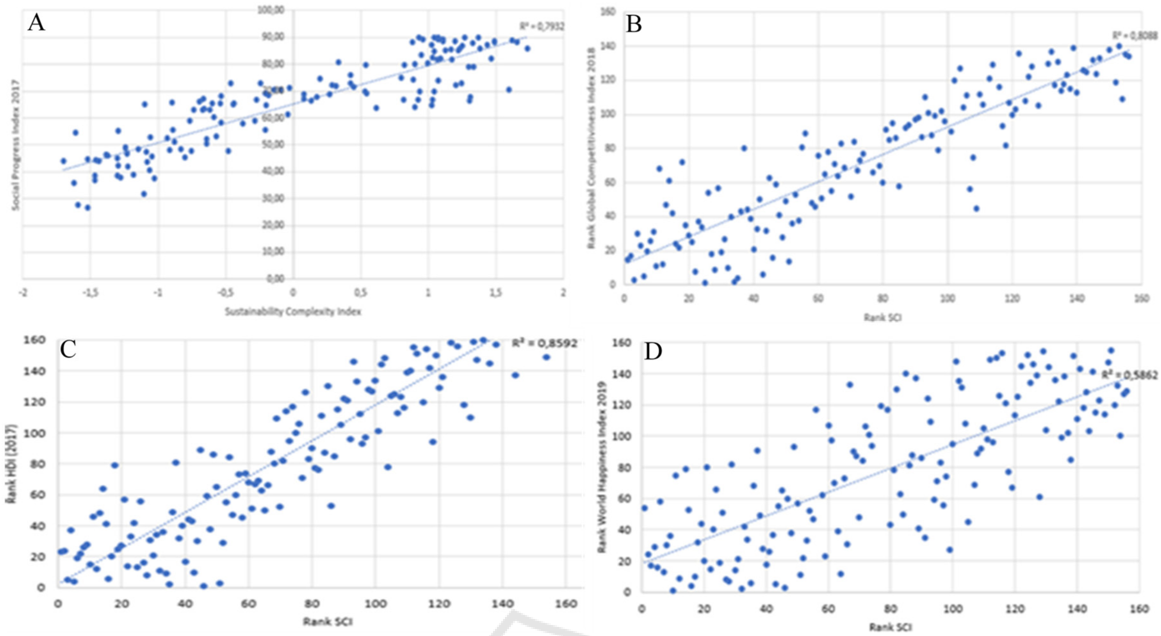

Figure 4: (A) Relationship between the SCI and the Social Progress Index (SPI). (B) Relationship between the SCI and the Global Competitiveness Index (GCI). (C) Relationship between the SCI and the Human Development Index (HDI). (D) Relationship between the SCI and the World Happiness Index (WHI).

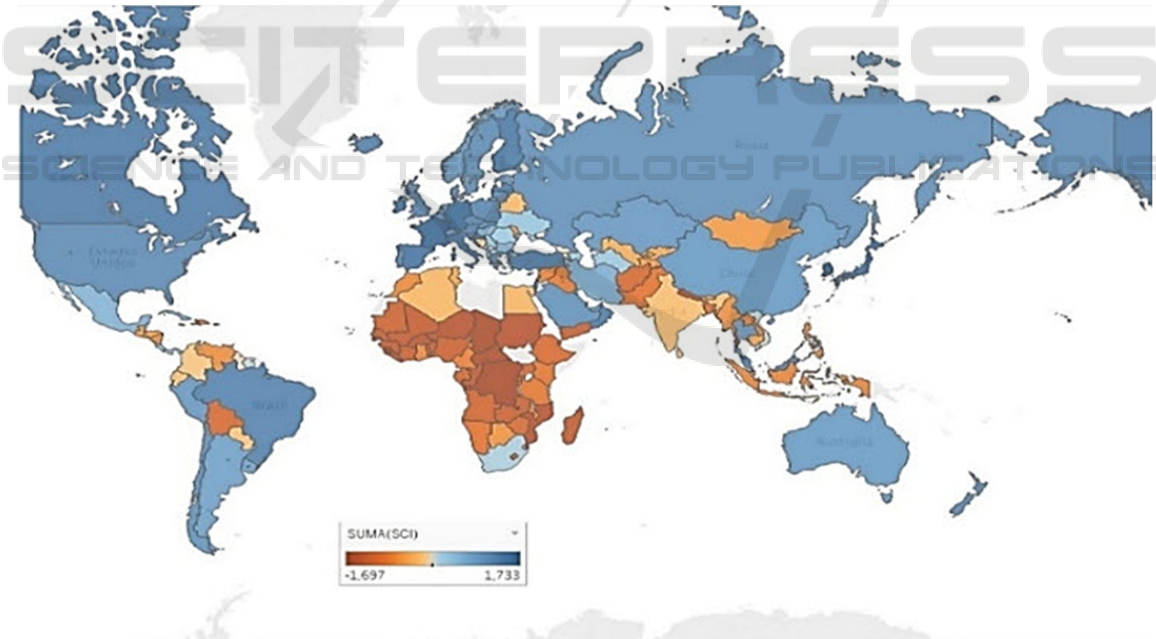

Figure 5: SCI heat map (World) – warmer colors reflects lower levels of sustainability complexity.

moderate levels of correlation with the indicators of the Worldwide

Governance Index Components (i.e. control of corruption, government effectiveness, political stability, regulatory quality, rule of law and voice and accountability).

Finally, in Fig. 5 we can observe the first attempt of implementation of the methodological approach proposed in this study, showing the results of the SCI for the 156 countries with available data in (Sachs et al., 2018).

From Fig. 5, it is clear that the biggest challenges for the accomplishment of the SDGs mainly remain in Africa and South East Asia. In South America, Bolivia and Venezuela present the lowest level of SCI.

Additionally, the Goal Complexity Index (GCI) has been measured, obtaining the results shown in Fig. 6. (darker colors reflects higher levels of GCI).

SDG	GCI
SDG12	1,65700123
SDG13	1,57927816
SDG17	1,22489455
SDG15	0,98658457
SDG6	0,56162096
SDG16	0,21317229
SDG11	0,1373906
SDG5	-0,0195058
SDG10	-0,07001025
SDG1	-0,07214902
SDG14	-0,19094156
SDG8	-0,28877772
SDG2	-0,6670405
SDG4	-0,7780202
SDG7	-0,9705432
SDG3	-1,24560092
SDG9	-2,05735319

Figure 6: GCI Index.

From the GCI, we conclude that the top 3, of more complex goals in the 2030 Agenda, are the SDG12 (Responsible Production & Consumption), SDG13 (Climate Action) and SDG17 (Peace, Governance & Partnerships). In the other hand, the least complex goals are SDG9 (Industry, Innovation and Infrastructure), SDG3 (Health & Wellbeing) and SDG7 (Energy).

In this context, an optimal strategy for countries could be following the sustainability complexity path, in order to fully achieve the 2030 Agenda, advancing from the accomplishment of less complex goals to more complex goals.

Finally, following studies should be oriented to analyze and to identify, through the use of network theory and product-space theory, how the accomplishment of a specific SDGs could lead to the accomplishment (or not) of another SDG.

5 CONCLUSIONS

The methodological approach proposed in this study shows strong evidence of its usefulness for the purposes of measuring the accomplishment of the SDGs, aligned with the 2030 Agenda. This complexity measures shows strong correlation with several development index that could explain the accomplishment of the SDGs in the different countries.

At the moment, the analysis of the SCI is limited to the availability of reliable data from the countries about their progress in the accomplishment of the different SDGs. It must be underlined, that the input data use in this methodology is based on SDG Report, published annually by the Sustainable Development Solution Network (SDSN) and the Bertelsmann Stiftung Foundation, that provides data that due to methodological limitations are not comparable year-by-year.

Nevertheless, we believe that the main contribution of this study is the innovative and interesting methodological approach to evaluate the progress in the accomplishment of the SDGs and the 2030 Agenda, offering a new tool to policy-makers and decision-makers to set development priorities and to identify opportunities or synergies to accelerate the accomplishment of the SDGs, based on complexity measures. Additionally, this index may provide a more synthetic summary to help predicting better adjustment policies.

Finally, considering that the methodology proposed in this study it is relatively new and the literature background of its implementation it is still relatively low, we suggest further studies in order to improve the experimentation and validation of the SCI and GCI for the analysis of the SDGs worldwide.

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