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A Systematic Study of Sustainable Development Goal (SDG) Interactions

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Key Points:
- Synergies, defined by positive correlations between indicator pairs, outweigh trade-offs (negative correlations) for most sustainable development goals (SDGs) and countries
- SDG 1 depicts synergies with most goals while SDG 12 shows trade-offs; SDG 3 has synergies with other SDGs in most countries and populations
- For attaining the SDGs, the synergies can be leveraged and the trade-offs need to be overcome by deeper changes in the current strategies

Supporting Information:
- Tables S1–S3

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Abstract Sustainable development goals (SDGs) have set the 2030 agenda to transform our world by tackling multiple challenges humankind is facing to ensure well-being, economic prosperity, and environmental protection. In contrast to conventional development agendas focusing on a restricted set of dimensions, the SDGs provide a holistic and multidimensional view on development. Hence, interactions among the SDGs may cause diverging results. To analyze the SDG interactions we systematize the identification of synergies and trade-offs using official SDG indicator data for 227 countries. A significant positive correlation between a pair of SDG indicators is classified as a *synergy* while a significant negative correlation is classified as a *trade-off*. We rank synergies and trade-offs between SDGs pairs on global and country scales in order to identify the most frequent SDG interactions. For a given SDG, positive correlations between indicator pairs were found to outweigh the negative ones in most countries. Among SDGs the positive and negative correlations between indicator pairs allowed for the identification of particular global patterns. SDG 1 (*No poverty*) has synergetic relationship with most of the other goals, whereas SDG 12 (*Responsible consumption and production*) is the goal most commonly associated with trade-offs. The attainment of the SDG agenda will greatly depend on whether the identified synergies among the goals can be leveraged. In addition, the highlighted trade-offs, which constitute obstacles in achieving the SDGs, need to be negotiated and made structurally nonobstructive by deeper changes in the current strategies.

1. Introduction

The publication of a comprehensive, and extensive, road map of targets and indicators underpinning the sustainable development goals (SDGs) in 2015 was a milestone for aligning not only developing countries but also developed ones on the path of sustainable development (United Nations General Assembly, 2015). The SDGs have set the 2030 agenda to transform the world by ensuring, simultaneously, human well-being, economic prosperity, and environmental protection. Comprising of 17 goals and 169 targets, SDGs aim at tackling multiple and complex challenges faced by humankind. Accordingly, they are implicitly interdependent and it may happen that conflicting interactions among the SDGs may result in diverging results (Nilsson et al., 2016).

In order to make policy happen, the dependencies among the goals in terms of potential interactions need to be evaluated, both across (Lu et al., 2015) and within the SDGs (Schmidt et al., 2015). This challenge is not new and similar concerns have been identified when attempting to align climate change adaptation and mitigation response (Smith & Olesen, 2010); poverty alleviation (Mathy & Blanchard, 2016); meeting the millennium development goals (MDGs) (Bue & Klasen, 2013); and balancing economic development, environmental sustainability, and social inclusion for human well-being (Ibisch et al., 2016; Sachs, 2012).

The holistic nature of the SDG framework implies that a large number of potential interactions across the 169 targets have to be considered by policy makers (Costanza et al., 2016; Rickels et al., 2016). Although a framework has been proposed to characterize SDG interactions (Nilsson et al., 2016), a systematic, data-driven analysis of interactions between all SDG indicators is currently missing. In their most general form, such interactions can be classified as *synergies* (where progress in one goal favors progress in another) or *trade-offs* (where progress in one goal hinders progress in another) and vice versa. We tie this semantic formulation of synergies and trade-offs to the results of a correlation analysis across all the official SDG indicators, accounting for all countries, and the entire time-frame for which data are available.

Accordingly, the objective of our study is to provide the first complete quantification of synergies and trade-offs as they occurred in the past to the present within and across the SDGs both at country and global scales. By doing so, we highlight the most commonly found trade-offs for which targeted and transformational action is required to overcome past trends and deliver the largest global benefits possible. Comparably, the analysis also identifies current synergies that are crucial to be reinforced and cross-leveraged in the future. The empirical framework on the evaluation of SDG interactions here presented makes a fundamental contribution to make policy happen for successful implementation of the SDG agenda.

2. Data and Methods

2.1. Data

The Inter-Agency and Expert Group on SDG Indicators endorsed a set of 230 individual indicators for monitoring the progress in achieving the SDGs (United Nations Economic and Social Council, 2016). Currently, United Nations Statistics Division (2016) provide data on 122 indicators for a total of 227 countries between the years 1983 and 2016 (Table S1). For 56 of these indicators country-disaggregated data in terms of gender, age, urban and rural population, or income groups is provided in order to "leave no one behind" (Stuart & Woodroffe, 2016). In this analysis we make use of both country and country-disaggregated data. Hence, for the same indicator multiple time-series are available depending on the level of disaggregation.

Indicator time-series are not available for all time steps and countries (see Tables S2 and S3). For around 85% of the countries, more than 80 time-series data are available since 1990. On average there are 175 time-series per country with a minimum of 6 time-series and a maximum of 265.

2.2. Analysis of Synergies and Trade-Offs

This study captures synergies and trade-offs in a statistical sense, that is, as the existence of a significant positive and negative correlation, respectively. The correlation analysis is carried out between unique pairs of indicator time-series, considering country and country-disaggregated data. For example, we analyze correlation between available data on *"maternal mortality ratio"* and *"portion of births attended by skilled health personnel,"* indicators of SDG 3 (*Good health and wellbeing*), for each country. The data pairs can belong to the same goal or to two distinct goals. This is done in order to capture both synergies and trade-offs happening within one particular goal, and positive/negative correlations between different goals.

Given the nature of an indicator, an increase or a decrease of its value in time carries different meanings for attaining the SDGs. For example, SDG 3 needs to be achieved by declining *"maternal mortality ratio"* and by increasing *"portion of births attended by skilled health personnel."* We assign a positive sign to indicators that are desirable to increase and a negative sign to those indicators that need a decline for meeting the SDGs (Table S1). This avoids false results like a trade-off in case of decreasing maternal mortality and increasing income. An analogous rationale would apply in cases of synergies.

The nonparametric Spearman's rank correlation (ρ) analysis is used to assess monotonic relationships between all possible combinations of the unique indicator data pairs for each country. Spearman's correlation coefficient (ρ) provides a measure to evaluate the strength of an association between two variables (Spearman, 1904). Unlike Pearson's correlation analysis, Spearman's analysis is able to capture nonlinear correlation between the variables and is less sensible to outliers (Hauke & Kossowski, 2011). Spearman's analysis is widely used to identify general relation beyond the linear correlation between two variables in various disciplines (e.g., Kellner & Hubbart, 2017; Sesnie et al., 2017; Sidney et al., 2017; Yoon, 2012). We carry out the correlation analysis only with the data pairs consisting of more than three data points. This reduces the chance of false detection of synergies/trade-offs resulting from a small number of data. The correlation with a p-value of less than 0.05 is considered as statistically significant.

A Spearman's ρ value greater than 0.6 is considered to indicate a synergy (positive association) between the two indicators, a ρ less than -0.6 is considered to indicate a trade-off (negative association). Hauke and Kossowski (2011) suggested avoiding over-interpretation of the ρ value as a measure of the strength of the associations between two variables. Therefore, indicator pairs with ρ values between -0.6 and 0.6 are not classified. The interaction between indicator pairs in each country fall into three categories: synergy, trade-off, or nonclassified. SDG indicators are used as proxies to characterize complex mechanisms and one cannot exclude confounding factors or spurious behavior between indicators. Our approach, therefore, aims at providing a first systematic overview on the SDG interactions.

2.3. Synthesizing Synergies and Trade-Offs across Scales

The results of the interactions between indicator pairs are then presented for each country and globally. At the global level, interactions of SDG indicators *within* one goal are quantified by the percentage of synergies, trade-offs, and nonclassifieds of indicator pairs belonging to the same SDG. Interactions *between* SDGs is given by the percentage of synergies, trade-offs, and nonclassifieds between indicator pairs that fall into two distinct goals. Similarly, SDG interactions at the country level are calculated based on the percentage of synergies, trade-offs, and nonclassifieds between all the indicator pairs of all the SDGs for the respective country. We choose the percentage to represent the interactions within and among the SDGs to avoid bias that may arise from variation in amount of available indicator data among the SDGs.

Afterward, we perform a global ranking of SDG pairs based on the percentage of synergies, trade-offs, and nonclassifieds. For this analysis only SDG pairs with more than 100 data pairs are considered. Similarly, we rank SDG pairs for each country individually following the similar approach but considering only the SDG pairs with at least 10 data pairs. Given that the rank of SDG pairs differ substantially from country to country, we derive a frequency rank of how often a given SDG pair fell within the top-five synergy or trade-off pairs across all countries. Finally, we map for each country the SDG pair that ranks highest in the top-five previously identified synergy or trade-off pairs.

By this, we analyze the SDG synergies and trade-offs under past and current technological and economic paradigms. Although the correlation does not necessarily imply causality, the analysis shows associated synergistic co-benefits and problematic trade-offs that exist among and within the SDGs under past and current conditions of socio-economic operation. This might not hold for the future. However, currently existing synergistic co-benefits need to be leveraged and problematic trade-offs need to be removed for sustainable transformation.

3. Results

3.1. Synergies and Trade-Offs within an SDG

Considering all countries, our analysis indicates that within each SDG synergies largely outweigh trade-offs (Figure 1). Particularly, SDGs 1 (*No poverty*), 3 (*Good health and wellbeing*), 4 (*Quality education*), 10 (*Reduced inequalities*), 12 (*Responsible consumption and production*), and 13 (*Climate action*) show synergetic relations with ρ values greater than 0.6 for 80%–90% of the data pairs. This indicates a broad compatibility of indicators, where progress in one indicator is associated with the fulfillment of another one in the same goal.

The large fraction of synergies within each SDG is consistent with previously highlighted linkages between some indicators. For example, recent studies show that a rise in the *"proportion of births attended by skilled health personnel"* and decline in the *"number of new HIV infections"* can contribute to a reduced *"maternal mortality ratio,"* indicators for the SDG 3 (Costello et al., 2004; Hogan et al., 2010; Jokhio et al., 2005). Additionally, pairs of disaggregated data for the SDGs mostly depict a positive correlation for all countries and enhance the percentage of synergies. For example, the large fraction of synergies within SDG 1 is partially due to synergies observed between disaggregated indicators such as *"proportion of population below the international poverty line, by sex, age, employment status, and geographical location."*

Our analysis also highlights the existence of negative correlations within the same goal. These are mainly observed within SDGs 7 (*Affordable and clean energy*), 8 (*Decent work and economic growth*), 9 (*Industry, innovation, and infrastructure*), and 15 (*Life on land*) for 25%–40% of the data pairs. According to our definition, progress in one indicator has been connected in the past and the present with an obstacle in fulfillment of another and vice versa. For example, *"proportion of population with access to electricity,"*, an SDG 7 indicator, has increased in some countries by expansion of nonrenewable energy sources (Wamukonya, 2003). This may not support an increase in *"renewable energy share in the total final energy consumption,"* another SDG 7 indicator. We can observe such significant negative correlation between these two indicators with ρ value -0.67 when all countries are considered.

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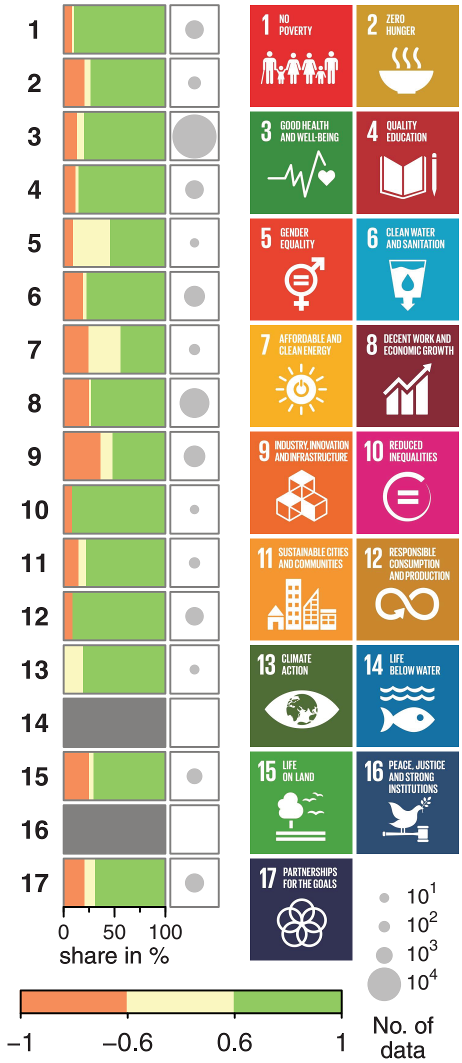

Figure 1. Observed synergies and trade-offs within an SDG. The color bars represent the shares of synergies (green), nonclassifieds (yellow), and trade-offs (orange) observed within a goal for the entire dataset. The gray bar depicts insufficient data for the analysis. The area of the circle in the boxes indicates the number of data pairs (see the legend for comparison). The SDGs are represented with the numbers in the left and the icons in the right. Within each goal the positive correlations largely outweigh the negative ones, however, negative correlations and nonclassifieds are also observed within all SDGs.

A similar logic is valid regarding the historical association of gross domestic product (GDP) per capita and material footprint of a country (Wiedmann et al., 2015). The sustainable development logic of SDG 8 calls for sustaining economic growth while improving resource use efficiency by reduction of material footprints. The opposite took place during the time-frame investigated with trade-offs observed between indicators *"annual growth rate of real GDP per capita"* and *"material footprint, material footprint per capita, and material footprint per GDP"* for 77% of the countries. The two examples make clear the existence of *intrinsic challenges* in achieving the SDGs due to the tight coupling (correlation) of some indicators.

3.2. Synergies and Trade-Offs Between SDGs

Among the SDGs both positive and negative interactions can be observed (Figure 2). A noticeable example is SDG 1 (*No poverty*) that is associated with synergies across most SDGs and ranks five times in the global top-10 synergy pair list (Figure 3, left). Reducing poverty is statistically linked with progress in SDGs 3 (*Good health and wellbeing*), 4 (*Quality education*), 5 (*Gender equality*), 6 (*Clean water and sanitation*), or 10 (*Reduced inequalities*) for 75%–80% of the data pairs. For SDG 3 a large fraction of synergies with various SDGs are also observed (Figure 2) and summarized by four appearances of the goal in the global top 10 synergy

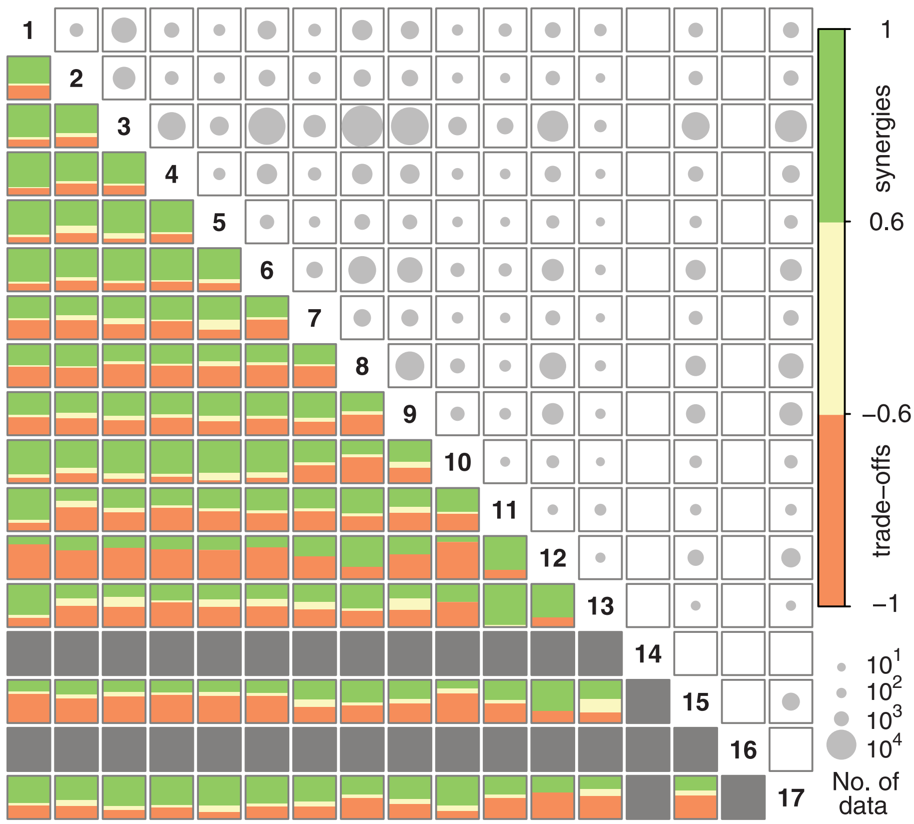

Figure 2. Observed synergies and trade-offs between the SDGs. The color bars represent the shares of synergies (green), nonclassifieds (yellow), and trade-offs (orange) observed between the SDG pairs for the entire dataset. The gray bar depicts insufficient data. The area of the circle in the boxes indicates the number of data pairs (see the legend for comparison). The SDGs are represented by the numbers in the diagonal. Both positive and negative correlations are observed among the SDG pairs with SDG 1 (*No poverty*) expressing synergies among most other SDGs. SDGs 12 (*Responsible consumption and production*) and 15 (*Life on land*) have mostly shown trade-offs with most other SDGs.

pair list (Figure 3, left). This underlines that improvement of global health and well-being has highly been compatible with progress in SDGs 1 (*Poverty reduction*), 4 (*Quality education*), 5 (*Gender equality*), 6 (*Provision of clean water and sanitation*), and SDG 10 (*Inequalities reduction*) based on more than 70% of the data pairs.

The observed positive correlations between the SDGs have mainly two explanations. First, indicators of the SDGs depicting higher synergies consist of development indicators that are part of the MDGs and components of several development indices (Jahan et al., 2015). Second, the observed higher synergies among some SDGs are an effect of having the same indicator for multiple SDGs. For example, *"number of deaths, missing persons, and persons affected by disaster"* and *"number of countries with national and local disaster risk reduction strategies"* are among the indicators for SDGs 1 (*No poverty*), 11 (*Sustainable cities and communities*), and 13 (*Climate action*). This is also a reason for observed high synergetic relation between SDGs 11 and 13. We apply our analysis for the repeated indicators to comply with the official indicator list.

Our analysis reveals the SDGs 8 (*Decent work and economic growth*), 9 (*Industry, innovation, and infrastructure*), 12 (*Responsible consumption and production*), and 15 (*Life on land*) to be associated with a high fraction of trade-offs across SDGs (Figure 2). These goals are currently in conflict with most other SDGs, antagonizing sustainable development. For instance, SDGs 8 (*Decent work and economic growth*) and 9 (*Industry, innovation, and infrastructure*) are negatively correlated with 12 goals (SDGs 1–7, 9, 10, 13, 15, 17) and nine goals (SDGs 1, 2, 4, 6, 8, 11–13, 15), for 40 to 60% of the data pairs, respectively. Similarly, SDGs 12 (*Responsible consumption and production*) and 15 (*Life on land*) frequently appear, seven and three times respectively, in the global top 10 trade-off pairs (Figure 3, right). SDG 12 has negative correlations with 10 goals (SDGs 1–7, 9, 10, 17) and SDG 15 with 12 goals (SDGs 1–6, 7–11, 17), respectively for 50%–90% and 40%–70% of the data pairs.

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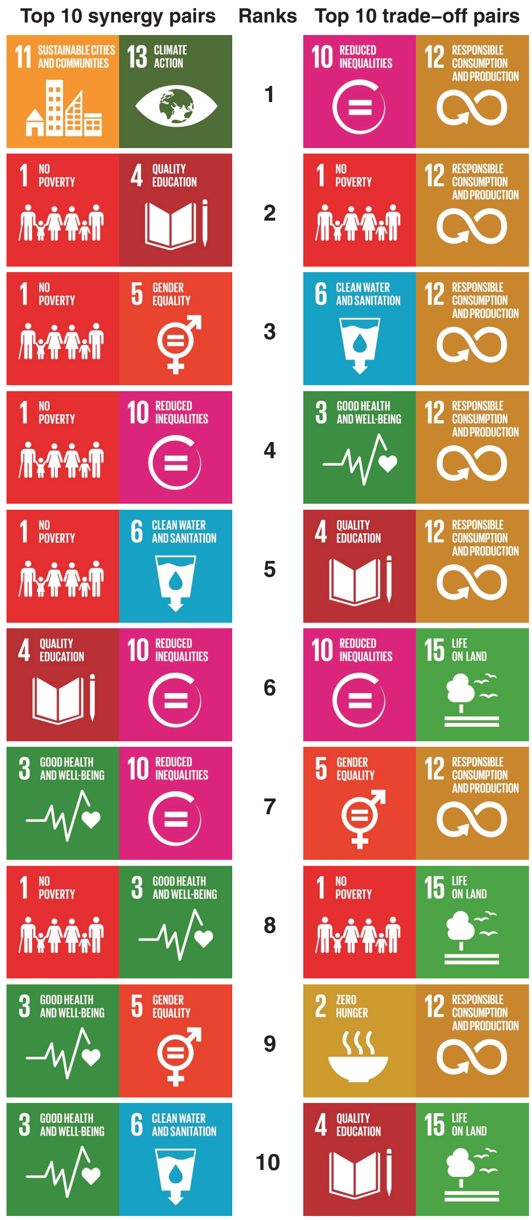

Figure 3. Global ranking of SDG pairs with high shares of synergies (left) and trade-offs (right) from top to bottom. SDGs 1 (*No poverty*), 3 (*Good health and well-being*) and 6 (*Clean water and sanitation*) dominate the global top 10 pairs with synergies. The global top 10 pairs with trade-offs either consist of SDG 12 (*Responsible consumption and production*) or 15 (*Life on land*).

Most trade-offs described beforehand can be linked to the traditional nonsustainability development paradigm focusing on economic growth to generate human welfare at the expenses of environmental sustainability (Sen, 1983). On average developed countries provide better human welfare but are locked-in to larger environmental and material footprints which need to be substantially reduced to achieve SDG 12 (*Responsible consumption and production*). In the past, a higher level of GDP and human development index (HDI) have contributed to improve health and nutritional status globally (Parkin et al., 1987; Pradhan et al., 2013) but also resulted in increasing greenhouse gas emissions and food waste (Costa et al., 2011; Hiç et al., 2016; Stoll-Kleemann & O'Riordan, 2015). Therefore, in these cases policies need to focus on societal transformation in order to break away from these locked-in relationships for the successful implementation of the SDG agenda.

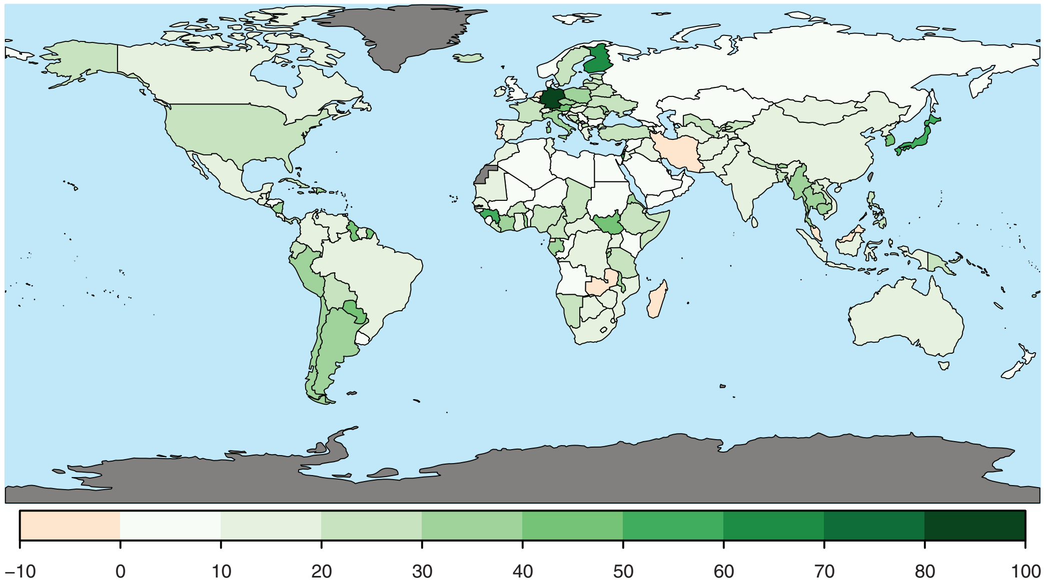

Figure 4. Global distribution of the difference between the share of synergies and trade-offs among the SDGs by country in percentage. Green color depicts countries with higher share of synergies than trade-offs, the opposite holds for orange color. The darker the color, the higher the difference is. The gray color depicts regions with no data or with less than 100 data pairs. For most countries positive correlations largely outweigh the negative ones. However, a larger trade-off share is also observed in some countries as indicated by lower differences. For all the countries the share of nonclassifieds is less than 20%.

3.3. Global Patterns of SDG Interactions

At the country level, our analysis indicates that positive correlations among the SDGs largely outweigh the negative ones for most countries (Figure 4). The observed share of synergies is larger than 40% for all the countries and more than 60% for around 70 countries. Similarly, the faction of trade-offs is less than 50% for almost all the countries and the trade-off fraction is less than 40% for around 140 countries. This implies that countries have a positive starting point to implement the SDG agenda due to relatively larger share of synergies than trade-offs among the SDGs. Notably, Finland, Germany, and Japan have a share of synergies at least 60% larger than that of trade-offs. These countries also rank better in the 2017 SDG index (Sachs et al., 2017) with a score above 80 out of 100. However, a high share of synergies does not necessarily mean a better score because the SDG index aims to summarize SDG baseline for countries and to compare their performances (Sachs et al., 2017).

SDG 3 (*Good health and well-being*) was found to have a higher share of synergies with other SDGs in most of the countries and the world population (Figure 5a). Notably, circa 2.7 billion people (year 2015) live in countries in which SDG 3 has substantial synergies with SDG 6 (*Clean water and sanitation*). Additionally, progress in both of these goals will positively contribute in fulfilling other SDGs (see associated pair in Figure 5a) for around 7.3 billion people. When all commonly found synergies are investigated, 6.8 billion people live in countries in which SDG 3 appears in one of the country-scale top synergy pairs. Hence, a paradigm shift prioritizing good health and well-being, for example, by inter-sectoral and prevention based approaches, will have a greater impact than the conventional approaches (Buse & Hawkes, 2015) and will also leverage attainment of other SDGs.

On the trade-off side, SDGs 3 and 12 are identified as a top trade-off pair in 121 countries, making it the most widespread trade-off across countries (Figure 5b). This is mainly driven by better health care being found in countries with larger material footprints. Approximately 3.4 billion people live in the countries where the historical dependency between health and sustainable consumption/production needs to be reinvented. Failing to do so, will likely result in a lock-in effect where countries having to opt for one of the goals to detriment of the other. Interestingly, our analysis has identified examples of synergies between SDGs 3 and 12, albeit for a reduced number of countries (Figure 5a). This highlights that particular lock-in effects between goals can, and have been, broken by past and current policies. The evidence calls for a deeper

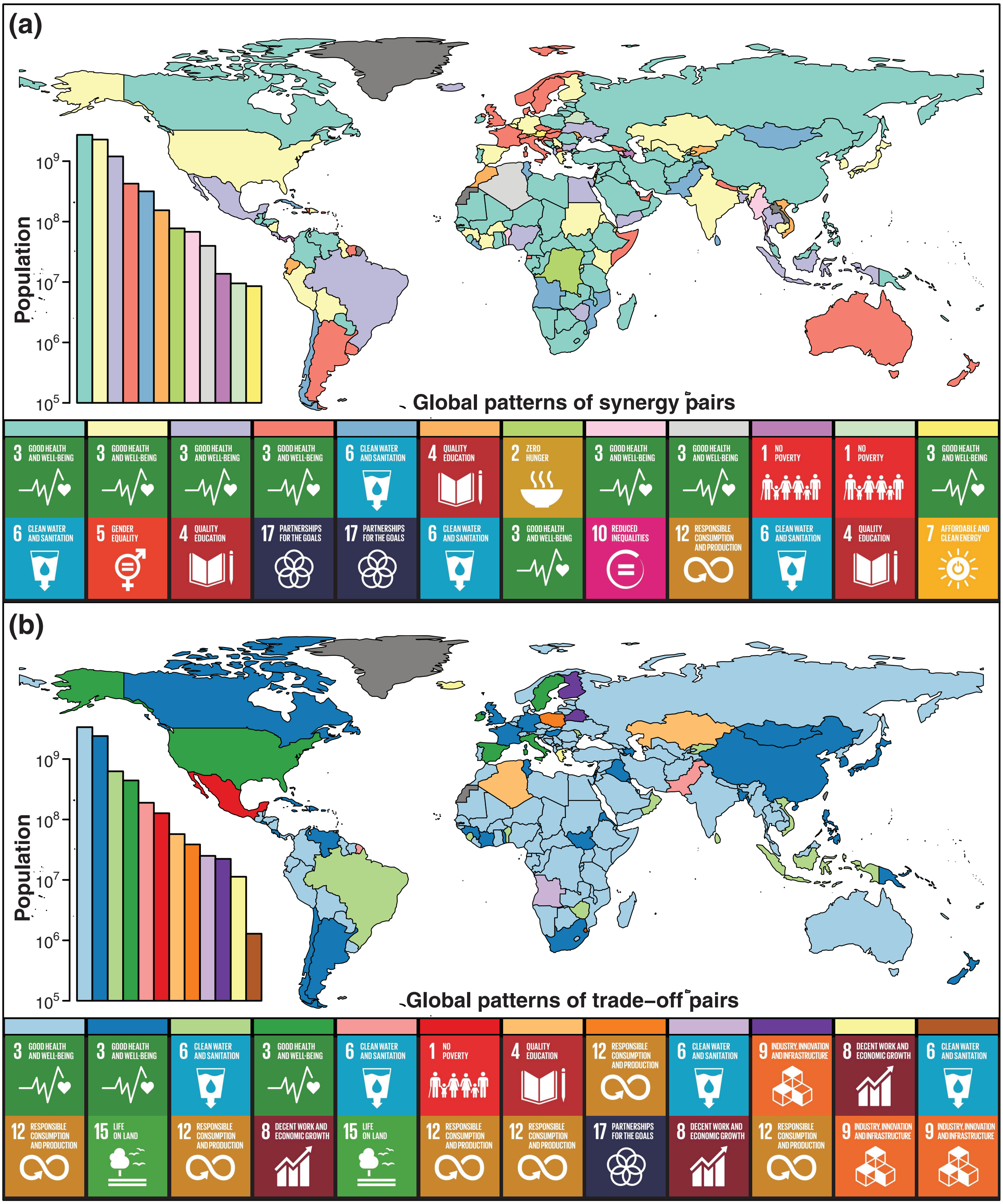

Figure 5. Global patterns of (A) synergy and (B) trade-off pairs with corresponding population for the year 2015 (barplot). The synergy between SDGs 3 (*Good health and well-being*) and 6 (*Clean water and sanitation*) is widely observed among countries with a total population of 2.7 billion. The trade-off between SDGs 3 (*Good health and well-being*) and 12 (*Responsible consumption and production*) is largely encountered among countries with a total population of 3.4 billion. The gray color depicts regions with no data or with less than 10 data pairs.

investigation of the development paradigm in targeted countries, which is fundamental to understand how relevant trade-offs can be mitigated.

SDG 3 is also an element in the second most common country scale trade-off, this time with SDG 15 (*Life on land*). This trade-off highlights that the achievement of good health standards in some countries coincided with the degradation of ecological systems. Examples of countries exhibiting this trade-off are China, South Africa, and Venezuela. Apart from these two major global patterns, the rest of the trade-off landscape is rather heterogeneous. Lager trade-offs between SDGs 6–12, 3–8, and 6–15, have only been identified for a few countries, although in terms of population the numbers can be substantial, that is, between 200 and 600 million people. These results imply that policy priorities for achieving the SDGs need to be differentiated among the countries based on the observed extent of SDG synergies and trade-offs in the considered country.

4. Discussion

The successful implementation of the SDG agenda is the only way forward to address the global sustainability challenge of ensuring human well-being, economic prosperity, and environmental protection. For this, all SDGs need to act as a system of interacting cogwheels that together move the global system into the safe and just operating space. No SDG will do that individually, and the whole SDGs should not be seen as an additive structure but as a system of synergistic re-enforcement. Hence, attainments of SDGs will greatly depend on whether synergies can be leveraged and trade-offs identified and tackled. Here, we devise a statistical formulation of the SDG synergies and trade-offs based on correlation analysis of development so far as a contribution to make the SDG agenda a success.

The potential synergies or trade-offs between the goals make the SDG interactions complex, as they are clearly not independent from each other. However, data granularity allowed us to analyze synergies and trade-offs within a given goal and divided by individual countries. Furthermore, by identifying synergies and trade-offs based on the official list of SDG indicators, we avoid the need to make use of proxy indicators, as commonly done in other approaches (Jakob & Steckel, 2016; Santangeli et al., 2015).

Our study highlights the existence of typically more synergies than trade-offs within and among the SDGs in most countries. This indicates a strong foundation for successfully implementation of the SDG agenda. Our analysis shows that SDG 3 (*Good health and well-being*) is mostly associated with synergistic co-benefits and SDG 12 (*Responsible consumption and production*) is largely linked with most problematic trade-offs among others. The observed synergies show a broad compatibility of SDGs where progress in one goal can leverage the fulfillments of the other goals. Therefore, policies fostering cross-sectoral and cross-goal synergetic relations will play a crucial role in operationalization of the SDG agenda (Nilsson et al., 2016).

Similarly, the observed trade-offs portray historical and current incompatibilities among the SDGs. Continuation of these may result in lock-in effects where progress in one of the goals may limit the fulfillments of others. For achieving the SDGs, these trade-offs need to be negotiated and made structurally nonobstructive, where possible. In some cases, a deeper structural change will be needed. For example, SDGs associated with higher human development and socioeconomic standards were traditionally conflicting with environmental protection goals. Learning from these past developments, policies should target for sustainable transformation by breaking away from these lock-in relationships and by creating new synergies. Policies on minimizing trade-offs with SDG 12 (*Responsible consumption and production*) have been suggested to be the most effective at leveraging the whole SDG agenda (Obersteiner et al., 2016). However, differentiated policies at different scales and countries are needed to foster synergies and to overcome trade-offs (Griggs et al., 2013), which is highlighted by the differences in top synergy and trade-off pairs identified on a global scale and for individual countries.

Our analysis also provides the starting point to interpret how SDGs might develop under different socioeconomic and climate scenarios. For example, the impacts of climate change that may constrain the achievement of SDGs, is expected to be mostly visible though the interactions of SDG 6 with their corresponding trade-off and synergy pairs (Szabo et al., 2016). Accordingly, changes in available freshwater resources triggered by climate change can either reinforce the trade-offs with SDGs 3, 15, and 9, or influence negatively the historical synergies with SDGs 1, 3, 4, and 17.

Compared to the recent report on SDG interactions (International Council for Science [ICSU], 2017), we obtain both agreeing and disagreeing results. ICSU (2017) applied expert judgment to identify causal and functional relations among the SDGs and mostly found synergies for the four considered SDGs 2, 3, 7, and 14. Our analysis also highlights similar larger synergies among other goals for SDGs 2 and 3. However, we obtain a mixture of synergies and trade-offs for the SDG 7. This implies that the positive interactions reflected on the theoretical level have not been fully achieved in the past. Therefore, we complement the qualitative SDG interaction studies by highlighting the current trade-offs instead of the future interactions after the achievement of SDGs. However, we were not able to analyze interactions for SDG 14 due to data scarcity, which was not the case for the qualitative approach. Therefore, enhancing our knowledge on SDG interactions will require intersecting both qualitative and quantitative approaches.

We also were able to distinguish SDG interactions for different countries in additional to the global aggregated picture. However, ICSU (2017) discards the possibility of having different countries displaying contrasting interactions between the same SDG pair. For example, although SDGs 3 and 12 have trade-offs in many parts of the world, there are countries in which this SDG pair have a synergistic relation (e.g., Algeria). In this sense, our analysis advances our understanding of current regional interactions among SDGs.

Although our study provides clear findings, the interpretation of results requires a discussion on the limitations nested in data sources and methodology used. Given that the current SDG indicator framework is still work in progress, our study is currently limited by the completeness of the SDG indicator database. Additionally, our analysis captures the existing SDG synergies and trade-offs based on currently available indicator data but do not necessarily indicate synergies and trade-offs for future conditions. This study highlights synergies that should be leveraged and trade-offs that should be overcome by transformative strategies to implement the SDG agenda. Our approach can also be applied to the updated SDG database after the development of the indicator framework.

We are aware that correlation does not imply causality. This means observed synergies between two SDG indicators could be independently related to another process driving both indicators and therefore resulting in correlations. However, because the correlation analysis is done for indicator pairs in each country individually, the existence of a large number of synergies (or trade-offs) suggests that the relation is widespread across many countries and most likely not appearing by chance. Hence, our findings on the SDG interactions attempt to reflect ongoing processes in most countries based on the multidimensional dataset. Furthermore, while the mechanisms generating synergies and trade-offs remain elusive in our analysis, we complement approaches using process-based models by investigating the entire option space in which synergies and trade-offs emerge.

The outcomes of our empirical analysis provide a sound basis for forthcoming works that wish to focus on the operationalization of synergies and trade-off models for the main patterns identified. This would allow to evaluate if leveraging the identified synergies could tip global megatrends into a safe and just operating space envisioned by the SDGs and which trade-offs constitute critical roadblocks that need to be circumvented.

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