



# Decoupling of SDGs followed by re-coupling as sustainable development progresses

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**Understanding the complex interactions among the Sustainable Development Goals (SDGs) is key to achieving all of the SDGs and ‘leaving no one behind’. However, research about dynamic changes of SDG interactions is limited, and how they change as sustainable development progresses remains elusive. Here, we used a correlational network approach and a global SDG database of 166 countries to analyse the evolution of SDG interactions along a progression of sustainable development measured by the SDG Index. SDG interactions showed nonlinear changes as the SDG Index increased: SDGs were both more positively and more negatively connected at low and high sustainable development levels, but they were clustered into more isolated positive connection groups at middle levels. The identification of a process of decoupling followed by re-coupling along the SDG Index strengthens our understanding of sustainable development and may help to suggest action priorities to achieve as many SDGs as possible by 2030.**

To tackle the most pressing issues facing humanity, such as climate change, poverty, inequality and quality education, the United Nations adopted 17 ambitious Sustainable Development Goals (SDGs) to stimulate actions in critically important areas for people, the planet and prosperity<sup>1</sup>. The 17 SDGs are integrated and indivisible, balancing the economic, social and environmental dimensions of sustainable development<sup>1</sup>. They cover all aspects of human life and interact in complex ways<sup>2</sup>. Actions for one goal may reinforce or offset the actions for another<sup>3,4</sup>, resulting in synergies and trade-offs among the SDGs. For example, using coal to improve energy access (SDG 7) will accelerate climate change (SDG 13) and disrupt health (SDG 3) through air pollution<sup>3</sup>. Given the ‘leave no one behind’ objective of the 2030 agenda<sup>3,4</sup>, understanding interactions among the SDGs is crucial when designing appropriate and efficient policies to implement them<sup>5,6</sup>.

Using systems thinking and analysis to assess the complex SDG interactions is at the forefront of sustainability research<sup>7</sup>. Multiple studies qualitatively scored and assessed SDG interactions by expert expertise<sup>3,8,9</sup> or text mining applied to official documents and the wording of SDG targets<sup>10,11</sup>, while other studies used pairwise correlations between the official indicator data for each SDG to quantitatively analyse relationships between SDGs<sup>4,5,12</sup>. Network analysis, which has been widely used in studies of complex systems (for example, health<sup>13</sup>, ecosystems<sup>14</sup> and societies<sup>15,16</sup>), is a holistic approach to explore the characteristics of SDG interactions<sup>17</sup> and their changes<sup>18</sup>. It provides clear visualization and conceptualization of interactions between variables and well-developed notions to characterize those interactions<sup>7</sup>. An array of network centrality measures (for example, degree centrality, betweenness centrality, eigenvector centrality and closeness centrality) can measure the importance of SDG goals or targets in the interaction network<sup>2,7,12,19</sup>, while network community detection can reveal the strongly connected groups of SDG goals or targets in the interaction network<sup>5,7,20</sup>. By characterizing the syner-

gies and trade-offs between SDGs, previous studies have identified the frequency of SDG interactions and the importance of individual SDG goals or targets at different scales<sup>4,5,21,22</sup>, as well as their differences across regions<sup>7,12</sup>. Comparisons among different groups of countries have shown that SDG interactions vary with a country’s socioeconomic characteristics, such as income, region and population composition<sup>2,9,17</sup>.

Although previous studies have helped policymakers and analysts grasp the complex and systemic nature of SDGs<sup>23</sup>, research about dynamic changes of SDG interactions, that is, how SDG interactions change as sustainable development progresses, is limited. By revealing dynamic changes of SDG interactions along sustainable development levels, we can determine the critical transformative stages of sustainable development, identify the hurdles and opportunities of sustainable development for countries at different levels and find specific action priorities for countries at different levels based on a better understanding of the sustainable development process. To fill this knowledge gap, this study addressed three major questions with a correlational network approach (Fig. 1a). First, did SDG interactions change along sustainable development levels and, if so, how? Second, which SDGs were more related to others, and how did the connections change along sustainable development levels? Third, which groups of SDGs tended to be achieved together, and how did the compositions of these groups change along sustainable development levels?

To address these questions, we used SDG data of 166 countries (Fig. 1b and Supplementary Table 1) from the *Sustainable Development Report 2020* prepared by the Sustainable Development Solutions Network and the Bertelsmann Stiftung<sup>24</sup>, which calculated scores for each of the 17 goals and the SDG Index (reflecting the overall sustainable development level) for each country, to build correlational networks along an SDG Index gradient. SDG interactions can be analysed at both goal and target levels<sup>2,12,19,21,22</sup>.

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